Evaluating in-person and online video teaching methods to introduce landscape equipment operation and safety and responses of ornamental groundcovers and turfgrass species to drought stress

by

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Abstract

Universities are adapting their teaching methods to progress with changes in technology. With these shifts in teaching, educators are interested in which methods are best for certain applications. A study was conducted to determine the efficacy of online vs. traditional hands-on learning with eight types of landscape equipment: power hedge trimmer, rotary push mower, de-thatcher, overseeder, ride-on zero-turn mower, sod cutter, string trimmer, and core aerifier. Results showed that students learn landscape equipment better in-person through hands-on learning, rather than relying only on videos. The survey also showed students prefer hands-on demonstrations to become more comfortable operating these pieces of equipment.

Water use in the landscape has become a more prevalent issue as the demand increases for more residential and commercial areas to be irrigated. This increase in water use indicates a need for drought tolerant plant species. We analyzed six ground cover species (*Dianthus caryophyllus, Lysimachia nummularia, Phlox subulata, Sedum album, Stachys byzantina,* and *Vinca major*) and three turfgrass species (*Bouteloua dactyloides, Festuca arundinacea,* and *Poa pratensis*) to evaluate their performance during drought and recovery. Results show *S. album* performed the best lasting an average of 157 d until reaching a visual quality rating of one. *S. byzantina, B. dactyloides, V. major, D. Caryophyllus* also performed well averaging 92, 51, 46, and 40 d, respectively, to a visual quality of one. *P. subulata, P. pratensis, F. arundinacea*, and *L. nummularia* performed the worst, averaging 35 d to decline to a visual quality rating of one. Following the dry down, the 60-d recovery period showed the following species recovered: *B. dactyloides* [58% Percent Green Cover (PGC)], *F. arundinacea* (45% PGC), *L. nummularia* (14% PGC), *S. album* (11% PGC), *P. pratensis* (10% PGC), and *V. major* (5% PGC).

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Lastly, and most importantly, I would like to express my deepest appreciation to my fiancé Jaime. She has been by my side through this chaotic time, and I am extremely lucky to have such a loving, encouraging, and thoughtful woman by my side. Thank you so much!

Dedication

I would like to dedicate this thesis to my family. My parents, Pam and Keith, my sisters Jenna and Darci, my two nieces, Lucy Bea and Eleanor, and most importantly my beautiful future wife, Jaime Luke.

Chapter 1 - Evaluating In-person and Online Video Teaching Methods to Introduce Landscape Equipment Operation and Safety

Abstract

Universities are adapting their teaching methods to progress with changes in technology. With these shifts in teaching, educators are interested in which methods are best for certain applications. In the horticulture realm, there are many studies describing the effects of online vs. traditional in-person learning. Most of these studies focus on plant identification and generic species knowledge of plants. The purpose of this study was to determine the efficacy of online vs. traditional hands-on learning with eight types of landscape equipment. The study was completed in the fall semesters of 2023 and 2024 at Kansas State University during the HORT 508 Business of Sustainable Landscape Management course. Each semester, the class was randomly divided into two groups with each group exposed to one of two teaching methods (hands-on and online videos). Eight commonly used pieces of landscape equipment were taught to the students: power hedge trimmer, rotary push mower, de-thatcher, overseeder, ride-on zero-turn mower, sod cutter, string trimmer, and core aerifier. Both the videos and the in-person teaching covered proper operation and safety for each piece of equipment. One group was given in-person, hands-on learning the first week, while the other group watched online videos over the same four pieces of equipment. The following week, the groups switched teaching method delivery and learned the other four pieces of equipment. The students were given a pre-/post-test to assess their comprehension of the equipment. They also participated in a survey after the experiment to show prior experience with the equipment and confidence after the labs. Results showed that students learn landscape equipment better in-person through hands-on learning,

rather than relying only on videos. The survey also showed students prefer hands-on demonstrations to become more comfortable operating these pieces of equipment.

Introduction

Many universities are increasingly providing online courses rather than in-person courses (Bigelow, 2009). Between 2009 and 2019, the enrollment at Kansas State University (K-State) for online classes increased roughly 1%, but between 2020 and 2025 increased by 4.5% (Office of Data, Assessment, and Institutional Research, 2025). With the 2020 COVID-19 pandemic, many programs were forced online (Melhorn et al., 2023). A study from The American Council on Education surveyed college and university presidents to gauge their changes in mode of instruction from fall 2019 to fall 2020. They found prior to the pandemic in fall 2019, 15% of institutions were predominantly online, while 70% were mostly in-person. After the outbreak of the pandemic, 55% of the institutions were online and 32% in-person (Turk et al., 2020). Due to these shifts, educators are more inclined to see whether online methods produce higher grades and/or are more favorable to students. Educators are continually interested in different online teaching methods they can use to enhance the learning achieved by students.

Distance education began over 30 years ago, one of the first studies involved the use of videodisc teaching modules at The Ohio State University (McCaslin & Na, 1994). These videodisc modules included plant identification and general plant knowledge about dogwoods and viburnums. The results of this study showed the students receiving videodisc learning received higher test scores on plant identification skills. Online learning methods have been expanding as technological advances have improved.

A study from 2004 offered online or in-person instruction in a greenhouse to learn about woody and herbaceous identification (Taraban et al., 2004). Students were randomly assigned to greenhouse or web instruction, and they found that online learning methods were not superior to live in-person instruction. The in-person students' mean scores were significantly higher than their online counterparts. Students were also surveyed and said they prefer live instruction rather than web-based instruction.

Texas Tech university offered a Principles of Horticulture course to teach herbaceous plant identification using live plants for half of the class and photographs sourced online for the other half of students (Teolis et al., 2007). They found that students scored higher on plant identification quizzes receiving live plant specimens rather than the students who were exposed to photographs of the same plants. Students' grade point average also had a positive correlation with their quiz scores.

A previous study showed students in the horticulture program at K-State had better test scores regarding turfgrass knowledge-based questions after receiving traditional teaching methods (in-person), rather than being taught through recorded PowerPoint lectures online (Peterson & Keeley, 2012). This result was contrary to the hypothesis tested, likely due to the minimal amount of time the students studied online. Bigelow (2009) found students spending greater than 19 hours online reviewing class material achieved equal grades to students who spent roughly 34 hours attending class in-person. Success in online-based classes is attainable if the student can put in adequate effort to study on their own.

Students who make an exceptional effort when studying can attain grades equivalent to their in-person counterparts. With the flexibility allowed through online learning methods, students can control the pace and frequency of learning. If the online resources provided to the students cover the material adequately, the students can be successful. With similar research comparing in-person, hands-on learning to online learning in horticulture to test their quiz scores, how do students perceive these online learning methods?

A study completed shortly after the 2020 pandemic surveyed undergraduate students enrolled in an agriculture program at the University of Tennessee after classes were forced online (Melhorn et al., 2023). The students participated in surveys at the beginning and end of the study to measure their perceptions of online learning. The beginning survey showed nearly 70% of students favored traditional in-person learning. Fifty-one percent of students surveyed felt the online methods would negatively affect their grades prior to the beginning of the semester. At the end of the study, this percentage rose to 56%. Students are hesitant to adjust to online methods and still favor traditional learning.

A turfgrass management course at North Carolina State University found that students enrolled in an online-based class scored equally to their in-person counterparts in all quantitative measurements of student performance (Shroeder-Moreno, 2007). However, surveys given after the course showed students were less comfortable with online learning and wanted more interaction with others in the class and the instructor. This study furthers the idea of students desiring in-person methods for course structure rather than only online methods.

Obvious trends in research regarding the positive effects of traditional learning compared to online learning are apparent; however, there is a lack of research in the realm of teaching landscape equipment operations to students. With many horticulture programs beginning to offer online certificates and degrees in addition to their traditional programs, it is important to find effective ways to teach laboratory components of courses. In this study, we evaluated in-person teaching methods compared to online video learning in a landscape management course, specifically when teaching about the operation of landscape equipment. The objectives of this research were to evaluate: 1) whether students could effectively operate landscape equipment after learning through online methods, and 2) the level of confidence the students have in operating the equipment before and after learning about the equipment based on the learning method. We hypothesized that student learning and confidence with operating the equipment would be greater with in-person instruction.

Methods

The study was conducted in the fall semesters of 2023 and 2024 in the HORT 508 Business of Sustainable Landscape Management class at K-State. The 2023 class contained two 1-hour lectures and a 2-hour lab per week. The 2024 class was a hybrid class which had online lectures the students could watch on their own time with a 2-hour lab one day per week. This study was administered during the lab portion of the class for both years. It was reviewed by the K-State Internal Review Board and approved under the criteria set forth by the Federal Policy for the Protection of Human Subjects, 45 CFR §104(d), category: Exempt Category 1.

The fall 2023 and fall 2024 classes were comprised of 18 and 14 students, respectively (n=32). The classes consisted of seniors (17), juniors (9), sophomores (5), and a master's student (1). Ninety-four percent of the students were majoring in horticulture with the majority (76%) of those students concentrating their studies in either landscape or turfgrass management. The remaining 24% were horticulture production students. The students in the study were primarily traditional students (<25 years old), with one student being older than this age threshold. The students were evenly split at 16 students each by gender, male and female. The class was randomly divided into two groups, group A and group B. Two teaching methods (in-person and online videos) were used to expose students to eight commonly used pieces of landscape equipment: 1) power hedge trimmer, 2) push rotary mower, 3) verticutter, 4) overseeder, 5) riding rotary mower, 6) sod cutter, 7) string trimmer, and 8) core aerifier. The in-person lab sessions were taught at K-State's Rocky Ford Turfgrass Research Center in Manhattan, KS. Students operated each piece of equipment during their respective in-person lab sessions.

The videos provided to the students in the online lab sections were educational videos gathered from YouTube. Each video was roughly three to four minutes long and covered aspects of starting the equipment, proper operating procedures, and importance of proper use of the individual pieces of equipment. The key points from the videos covering safety and operating procedures were the main objectives for the in-person lab sessions. The videos for each lab were posted to Canvas, the Learning Management System (LMS) used at K-State, at the start of class time for each lab, respectively, and were open to viewing for one week. The videos were only open to the online group of students for the particular week they were assigned to the online learning module. Students in the online group each week were instructed to watch the videos; however, there was no incentive given for the students to watch the videos.

The study consisted of two lab sessions each year. Prior to the start of the study, the students received a pre-test to evaluate prior knowledge of landscape equipment procedures and safety protocols. During the first week, Group A experienced in-person (hands-on) training consisting of proper safety and operation of four pieces of equipment, while Group B was provided videos on the same pieces of equipment in Canvas (Instructure, 2024). The equipment used in week one included a power hedge trimmer, push rotary mower, verticutter, and overseeder both years. For the following week, the groups switched learning methods (i.e., the in-person students changed to online and vice versa). The second set of equipment included a riding rotary mower, string trimmer, core aerifier, and sod cutter. At the end of the two weeks of labs, the students participated in a post-test to evaluate the change in responses from the pre-test, if any. The students were provided with a Qualtrics (2024) survey to assess the students' comfort, understanding, and prior knowledge of proper equipment proceduresTable 1.1. Survey questions presented to students through Qualtrics after the conclusion of both in-person and online lab sessions.

The pre- and post-tests contained two types of questions: 1) equipment safety, and 2) correct equipment operating procedures. The safety portion included questions about proper PPE (personal protective equipment) to wear, general questions about how to operate safely, and hazards to avoid while operating landscape equipment. The operating procedures section of the tests contained questions solely covering the eight individual pieces of equipment. The proper method to start the equipment, how to operate effectively, and the importance or proper use of the specific piece of landscape equipment. The students were informed their scores for the pre- and post-test will not be reflected in their overall grade for the class. However, they received ten participation points for completing the tests and survey.

A survey was conducted the following week after the completion of the two lab sessions (Table 1.1). The survey was comprised of generic demographic questions, questions to understand if the students had previous experience with individual pieces of equipment prior to the study, preference of teaching method, and confidence in operating the landscaping equipment after participating in the labs. Students responded to questions and were given a five-point Likert-scale for both the prior experience and post lab confidence in using the eight pieces of equipment.

Data Analysis

The pre- and post-tests mean scores of both samples of students (fall 2023 and 2024) were compared for each piece of equipment. The scores were analyzed using Welch's two sample t-test using R Studio (2023). The paired t-test was also used to find significance between individual pieces of equipment in R Studio (2023).

The survey results from prior experience and post lab confidence survey questions were put into SAS software (2022), then fitted into the following linear regression model:

$$y_{it} = IP_{it}\beta_1 + \gamma_1 M1_{it} + \gamma_2 M2_{it} + \gamma_3 M3_{it} + \gamma_4 M4_{it} + \gamma_5 M5_{it} + \gamma_6 M6_{it} + \gamma_7 M7_{it} + \alpha_i + \epsilon_{it}$$

Where y_{it} is the dependent variable showing the difference between the students' post and prior Likert responses; IP_{it} is an independent variable showing if the student learned about the equipment in-person, and β_1 is a regression coefficient to amplify the in-person variable; $(M1 - M7)_{it}$ refer to each individual piece of equipment (M represents equipment or machine) and it's corresponding regression coefficient (γ_{1-7}); student fixed effects are represented by α_i; and ϵ_{it} is the error term. To avoid multi-collinearity, the riding rotary mower (M8) was dropped from the equation as it had the least amount of increase from prior to post survey results. To see the potential increase of in-person students compared to online, we ran the interaction of in-person by each individual equipment (M1-M7) in SAS.

Results and Discussion

Pre- and Post-test Results

Students scored higher on their post-test compared to their pre-test. The overall total mean score increased for both in-person (11%) and online (5%) modes of instruction (Table 1.2), indicating students retained more information about the safety operations of the equipment during the in-person lab sessions compared to online videos. Additionally, more intricate, less commonly used equipment (i.e., overseeder, hedge trimmer, sod cutter, core aerifier) had an increase in means from pre-test to post-test for the in-person session compared to online. The individual equipment scores for the in-person teaching increased significantly for the overseeder

(31%), hedge trimmer (20%), sod cutter (15%), and core aerifier (11%) compared to online learning (Table 1.2). This is likely because many students lacked prior exposure to the equipment and gained more knowledge and experience during the in-person lab sessions than with the other equipment. The more commonly used equipment (i.e., riding rotary mower, push rotary mower, and string trimmer) had little to no change in scores from pre-test to post-test for both in-person and online students (Table 1.2).

While there was a significant increase for in-person pre-test to post-test scores, the individual in-person equipment increases from pre-test to post-test were only significant for half of the equipment that was taught. The sample size of n=32 may be a limiting factor. It is possible that a larger sample size is needed to find significance for more of the individual pieces of equipment. More research is needed to understand which types of equipment, such as more intricate or less common, would be suitable for online learning. Our method of each student being able to experience the individual equipment only in-person or online is another limitation of the study. We are not able to see how the student would learn through both in-person and online methods with a specific piece of equipment.

Survey Results

Students in the in-person labs increased their Likert-scale responses for confidence in operating the equipment more than their classmates participating in the online labs for their respective lab sessions. In-person Likert responses increased by 0.270 points on a 1-5 scale compared to their online counterparts for all landscaping equipment (Table 1.3). Overall, students felt more confident operating the equipment after the in-person labs compared to those learning online. Students provided supporting comments on this claim in response to question nine (Table 1.1) on the survey (Table 1.4). Specific to each piece of equipment, students generally increased their Likert scores regardless of being in-person or online by the following: overseeder and hedge trimmer by 1.203 points, core aerifier by 1.047 points, verticutter by 0.984 points, and sod cutter by 0.953 points. This indicates these types of equipment are traditionally less commonly operated by landscape students prior to experiencing this lab and students gained more confidence with these pieces of equipment compared to other equipment in the study. More commonly used equipment, string trimmer and push rotary mower, increased by only 0.609 and 0.422 points, respectively (Table 1.3). Overall, students gained more confidence after our lab sessions regardless of the teaching method (in-person or online).

Core aerifier had the greatest increase from prior experience to post confidence for in-person students at 0.807 points (Table 1.5 and Figure 1.1). Additionally, the verticutter and hedge trimmer had a 0.703 increase. The overseeder and sod cutter had less of an increase at 0.578 and 0.495, respectively, while the push rotary mower and string trimmer did not see a significant increase. This is similar to the pre-test to post-test results (Table 1.2), where the difference of change in in-person and online scores did not significantly increase for these two more commonly used pieces of equipment.

We did not incentivize the videos (i.e. grades for participation, graded quizzes, etc.) for the online students, which may be a limitation of the study. Thirty-four percent of the students did not watch any of the videos and 41% (sum of two video watching trend questions; "I watched some of the videos part way through", and "I watched all of the videos part way through") watched some portions of the videos (Figure 1.2). Only eight (25%) of the students in the study claim to have watched all of the online videos in their entirety. Interestingly, of the eight students, seven were female. The lack of video watching may have led to students receiving less of an increase in scores from pre-test to post-test and contributed to less post-lab confidence in the survey results.

Summary

The results indicate the need for in-person instruction rather than online methods for intricate equipment. For the string trimmer, push rotary mower, and riding rotary mower, which did not have significance being taught in-person, solely online methods may suffice. However, in-person methods to teach landscape equipment may be the desired route to educate landscape horticulture students. Student’s success with online learning could be improved with adequate effort watching the online videos. Incentivizing or grading the participation of student’s online video watching may have increased the pre- and post-test scores and their increase in Likert responses from prior experience to post confidence levels. Overall, in-person learning for hands-on activities seems to be essential to the success and confidence of students.

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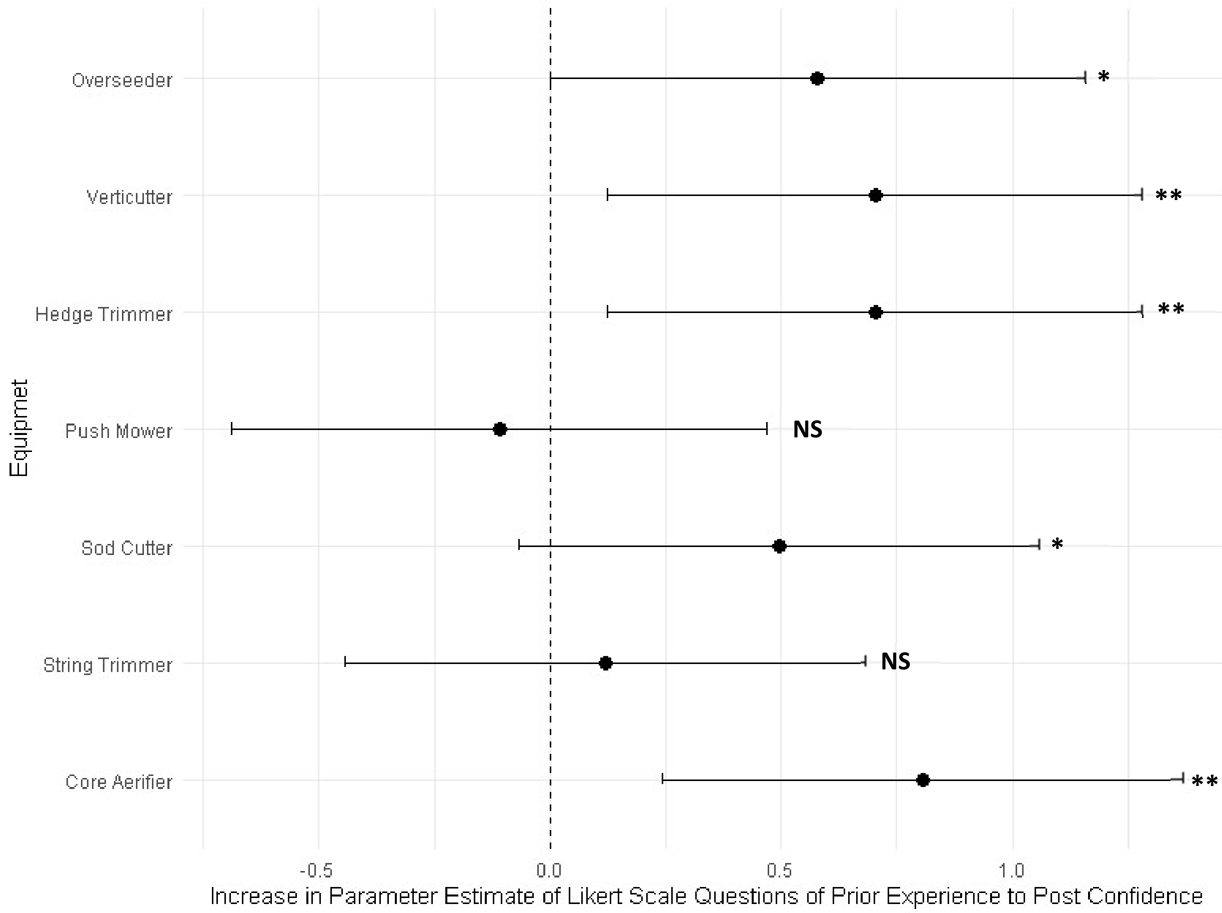
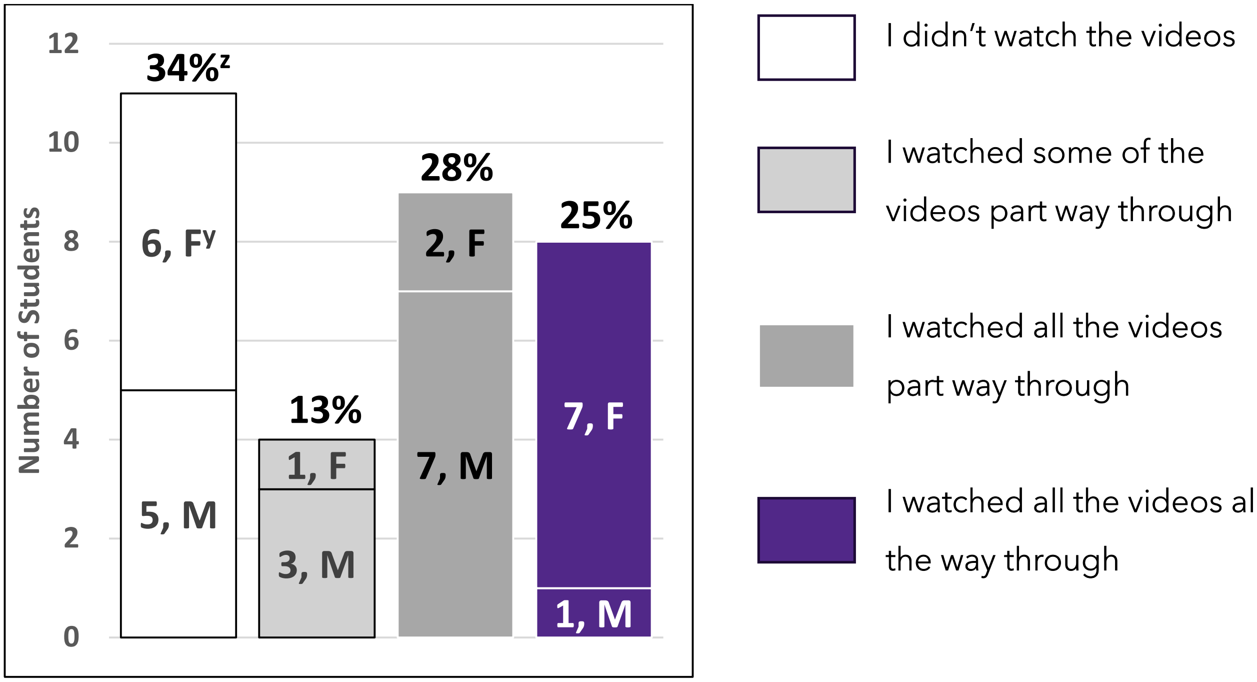
Figures

Figure 1.1. In-person compared to online marginal effects of prior experience to post confidence Likert scale survey questions.



note. All pieces of equipment are compared to the riding rotary mower, represented by the dashed vertical line. The horizontal solid lines are the parameter estimates of each individual equipment and their standard errors.
Likert scale questions for prior experience: 1= no or very little experience; 2= some experience; 3= moderate experience; 4= adequate experience 5= lots of experience
Likert scale questions for post confidence: 1= little confidence; 2= some confidence; 3= moderate confidence; 4= adequate confidence, 5= high confidence
Significance is indicated as follows: *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.1$, and NS=Not Significant

Figure 1.2. Student's video watching trends for their online lab sessions. Students were given access to videos during the online lab sessions for one week starting at the beginning of their respective lab sessions.



note. z Percentage of the total students in the study
y count of male (M) and female (F) students for each video watching trend

Tables

Table 1.1. Survey questions presented to students through Qualtrics after the conclusion of both in-person and online lab sessions.

Question number	Survey questions
1	How old are you?
2	What is your gender?
3	How many semesters have you been on a college campus?
4	Which equipment did you learn about in-person at Rocky Ford Turfgrass Research Center?
5	Which equipment did you learn about online by watching videos?
6	Which equipment did you have experience operating prior to the lab sessions? If you had prior experience, how would you rate your experience on a scale of 1 to 5? (with 1 being very little experience and 5 being lots of experience)
7	How confident do you feel operating each piece of equipment safely and effectively after the labs? How would you rate your confidence level on a scale of 1 to 5 (with 1 being not confident and 5 being extremely confident)?
8	Which teaching method (in-person or online videos) did you prefer to learn about the safety and operation of commonly used landscape equipment?
9	Why did you prefer the teaching method (in-person or online) you chose in the question above?
10	Why did you not prefer the other teaching method (in-person or online)?
11	Did you watch the videos? Which selection below most closely fits how you watched the videos?

Table 1.2. **Mean increase of pre-test to post-test questions relating to proper operating procedures for in-person and online teaching methods for eight pieces of landscape equipment.**

	In-person			Online			
	Pre	Post		Pre	Post		
	Score %		Δ_{IP}^{z}	Score %		Δ_{OL}^{y}	Δ_{IP}- Δ_{OL}^{x}
Overseeder	47	88	41	62	72	10	31^{***}
Verticutter	67	72	5	71	81	10	-5^{NS}
Hedge trimmer	79	92	13	98	91	-7	20^{*}
Push rotary mower	88	93	5	87	90	3	2^{NS}
Sod cutter	64	87	23	65	73	8	15^{**}
String trimmer	89	92	3	91	93	2	1^{NS}
Core aerifier	65	78	13	69	71	2	11^{*}
Riding rotary mower	91	87	-4	93	92	-1	-3^{NS}
Overall total score	75	86	11	78	83	5	6^{*}

note. z Change in in-person (IP) scores from pre-test to post-test.
y Change in online (OL) student scores from pre-test to post-test.
x Difference of change in in-person scores and change of online scores (IP-OL).
Significance is indicated as follows: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, and NS=Not Significant

Table 1.3. Linear regression coefficient estimates for student's in-person and online Likert responses for in-person students and each individual piece of landscape equipment.

Identifier^{z}	Variable	Parameter estimate^{y}	Standard error
IP	In-person	0.270**	0.1233
M1	Overseeder	1.203***	0.2465
M2	Verticutter	0.984***	0.2465
M3	Hedge trimmer	1.203***	0.2465
M4	Push rotary mower	0.422*	0.2465
M5	Sod cutter	0.953***	0.2465
M6	String trimmer	0.609**	0.2465
M7	Core aerifier	1.047***	0.2465

note. z Identifying label for each independent variable for the multiple linear regression equation. Each piece of equipment or machine (M) was included in the equation except for the riding rotary mower (M8) which was dropped to avoid multicollinearity.
y The parameter estimate column shows the increase in prior to post Likert scale questions per individual equipment. Student fixed effects were taken to group individual responses.
$R^2 = 0.634$ [Total observations=256 (students X equipment)].
Significance is indicated as follows: *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.1$

Table 1.4. Selected student responses to survey question nine [Why did you prefer the teaching method (in-person or online) you chose in the question above?] from Table 1.1.

Student number	Student responses
1	Because I actually participated and was way more focused and I'm a hands-on learner.
2	The action and movement associated with the in-person teaching helps me recall the machinery and the experience
3	Learning in person provided the opportunity for hands on experience, which I've learned helps me remember and learn better than videos.
4	I prefer in-person because I pay better attention and am able to ask questions. I'm also a visual learner so I like being able to have a hands-on approach.
5	I already knew how to operate the equipment

Table 1.5. Linear regression coefficient estimates of the student's interactions between in-person and each individual piece of landscape equipment Likert scale survey questions.

Identifier[z]	Variable	Parameter estimate[y]	Standard error
IP M1	In-person x overseeder	0.578*	0.2955
IP M2	In-person x verticutter	0.703**	0.2955
IP M3	In-person x hedge trimmer	0.703**	0.2955
IP M4	In-person x push rotary mower	-0.109[NS]	0.2955
IP M5	In-person x sod cutter	0.495*	0.2872
IP M6	In-person x string trimmer	0.120[NS]	0.2872
IP M7	In-person x core aerifier	0.807***	0.2872

note. z Identifying label for each independent variable for the multiple linear regression equation. Each piece of equipment or machine (M) was included in the equation except for the riding rotary mower (M8) which was dropped to avoid multicollinearity.
y The parameter estimate column shows the increase of in-person compared to the online students for prior to post Likert scale questions per individual equipment. Student fixed effects were taken to group individual responses.
$R^2 = 0.588$ [Total observations=256 (students X equipment)].
Significance is indicated as follows: *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.1$, and NS=Not Significant

Chapter 2 - Responses of Ornamental Groundcovers and Turfgrass Species to Drought Stress

Abstract

Water use in the landscape has become a more pressing issue as demand increases for irrigation in residential and commercial areas. This increase in water use indicates a need for drought-tolerant plant species. Ornamental ground covers can provide an alternative to traditional turfgrass and may provide water savings. Several studies have evaluated drought tolerance of turfgrass species, including *Poa pratensis* and *Festuca arundinacea*. Ground cover species, however, have less research available regarding drought tolerance. In this study, we analyzed six ground cover species (*Dianthus caryophyllus, Lysimachia nummularia, Phlox subulata, Sedum album, Stachys byzantina,* and *Vinca major*) and three turfgrass species (*Bouteloua dactyloides, Festuca arundinacea,* and *Poa pratensis*) to evaluate their performance during drought and recovery. We conducted two studies to simulate drought conditions in a greenhouse at Kansas State University from April 2024 to November 2024 and May 2024 to January 2025. Plants were not watered during drought until they reached a visual quality rating of one (1-9 scale, 1=dead/dormant and 9=best visual quality). Normal watering resumed for 60 d to simulate a recovery period following the drought period. Data collected three times per week during the drought period included visual quality rating (1-9), pot weight (g), and volumetric water content (θ_v). We collected leaf water potential (Ψ_{Leaf}) and stomatal conductance (g_s) once a week. Results show *S. album* performed the best, lasting an average of 157 d until reaching a visual quality rating of one. *S. byzantina, B. dactyloides, V. major, D. Caryophyllus* also performed well averaging 92, 51, 46, and 40 d, respectively, to a visual quality of one. *P. subulate, P. pratensis, F. arundinacea*, and *L. nummularia* performed the worst, averaging 35 d

to decline to a visual quality rating of one. Following the dry down, the 60-d recovery period showed the following species recovered: *B. dactyloides* [58% Percent Green Cover (PGC)], *F. arundinacea* (45% PGC), *L. nummularia* (14% PGC), *S. album* (11% PGC), *P. pratensis* (10% PGC), and *V. major* (5% PGC). None of the other species recovered through the recovery period. Results indicate *S. album, B. dactyloides,* and *V. major* may perform the best in landscapes experiencing drought. *F. arundinacea, L. nummularia,* and *P. pratensis* may be good options as well if acute drought periods (<40 d) occur.

Introduction

Efficient water use has become a major issue in the United States. The volume of subsurface water in the United States has decreased by nearly 1000 km^3 from 1900-2008 (Konikow, 2015). The United States Geological Survey (USGS) reported irrigation water withdrawals [includes all agricultural and horticultural (golf courses, parks, nurseries, turf farms, cemeteries, etc.) applications] were 435 billion liters of water per day ($l\ d^{-1}$) in the U.S., and 11 million $l\ d^{-1}$ in Kansas throughout 2010 (Maupin et al., 2014). Some residential homes can use a large amount of water to irrigate landscape plants. For example, residential homes used nearly 1500 $l\ d^{-1}$ in Puget Sound, Washington, with approximately half of that being applied outdoors in the lawn and landscape (Smith & Brown, 2003). The Residential End Users of Water, Version 2 (REU2016) surveyed 838 U.S. homes and found the average outdoor water use to be 191,163 liters per house per year ($l\ h^{-1}\ y^{-1}$) of the 382,327 $l\ h^{-1}\ yr^{-1}$used at the entire home level (interior and exterior water use) (DeOreo et al., 2016). Residential water use on a national level varies greatly, with the northeast U.S. using less water than the southwest U.S. Maine's average household uses 379 $l\ d^{-1}$ while Utah averages 1,787 $l\ d^{-1}$ (Emrath, 2000). As urban sprawl continues and water supplies become more limited, water conservation efforts in the lawn and landscape become increasingly necessary.

Due to the reduction in stored water resources, environmental water programs have been formed to lessen the amount of water waste. The Environmental Protection Agency (EPA) launched the Water Sense Program in 2006 to help decrease the amount of water waste and inform the public about water efficiency and efficacy. This program includes interior water faucets to exterior irrigation emitters (McNeil, 2008). Urbanization is another factor that increases water use, which has increased in the U.S. from 81.1% in 2012 to 83.8% in 2022 (United Nations Population Division, 2022). It is important to educate the public to apply less water to landscape areas. A possible way to reduce water in the landscaping would be to use drought-tolerant plant material.

Turfgrass lawns make up roughly 20 million acres of lawns in the United States (R. Braun, personal communication, 2025). While not all turfgrass lawns receive irrigation, this large acreage creates opportunities to evaluate various turfgrass species and cultivars to determine recommendations that require less water. Kentucky bluegrass (*Poa pratensis* L.) cultivars, 'Mallard' and 'Diva', showed high drought tolerance compared with other cultivars, these two did not decrease to 50% green cover until 40 days after irrigation (DAI) was withheld (Richardson et al., 2008). Tall fescue [*Festuca arundinacea* Schreb.; syn. *Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] decreased to 50% green cover at 47 and 51 DAI withheld on average among 12 different cultivars and took an average of nine days to return to 50% green cover (Karcher et al., 2008). Buffalograss [*Buchloë dactyloides* (Nutt.) Engelm; syn. *Bouteloua dactyloides* (Nutt.) J. T. Columbus] cultivar 'Prairie' showed high drought avoidance by developing a deep rooting system, a low evapotranspiration (ET) rate, and a high osmotic adjustment while soil water content declined (Qian & Fry, 1997). While there are ample amounts of research regarding turfgrass water use and drought tolerance (Braun et al., 2022a, 2022b; Colmer & Barton, 2017), we need further research in the realm of ornamental groundcovers to determine if they could be an alternative to turfgrass for non-recreational areas in the landscape.

White stonecrop (referred to as sedum) (*Sedum album* L.), a succulent plant, incorporates the crassulacean acid metabolism (CAM) photosynthetic pathway that allows it to keep the leaf water potential unchanged for a longer time throughout drought stress (Sayed et al., 1994). This reduces the amount of water used during hot times of the day. With this ability, sedum may be a good alternative in areas that experience severe drought conditions. In a 2013 study, sedum maintained an acceptable visual quality rating through week six of a dry down (J. Domenghini et al., 2013). This same study, which used a greenhouse dry down to simulate an extended drought period, found greater periwinkle (referred to as vinca) (*Vinca major* L.)] to recover to 35% green cover after reaching the lowest visual quality rating. It took vinca roughly 65 days to reach the lowest visual quality rating after irrigation ceased. Vinca could potentially be a good candidate for landscapes experiencing prolonged droughts.

Understanding ground covers and their ability to tolerate drought is a needed area of research. The objectives of this study were to: 1) evaluate drought stress of three turfgrass and six groundcover species using visual quality, leaf water potential (Ψ_{Leaf}), volumetric water content (θ_v), and stomatal conductance; and 2) evaluate the recovery using visual percent green cover of the same species after reaching the lowest visual quality rating.

Materials and Methods

Six ornamental ground cover species [dianthus (*Dianthus caryophyllus* L.), creeping Jenny *(Lysimachia nummularia* L.), creeping phlox (referred to as phlox) (*Phlox subulata* L.), sedum, lambs ear (*Stachys byzantina* L.), and vinca and three turfgrass species (buffalograss, tall fescue, and Kentucky bluegrass) were evaluated in a greenhouse through an extended period with no irrigation. Three of these species (Kentucky bluegrass, sedum, and vinca) were selected for this study due to a previous study by Domenghini et. al. (2013) where these three species recovered from a severe drought during the recovery phase of their study.

Two experiment runs were completed in the spring/summer of 2024 in a greenhouse at Throckmorton Plant Sciences Center, Kansas State University (KSU), Manhattan, KS (N 39º 11' 40", W 96º 35' 5"). The first experiment run was initiated in early spring (Run A) with the second beginning in later spring (Run B). Nursery containers (25 cm diameter x 29.5 cm height) were used to establish the ground covers and turfgrass ensuring roots would not be restricted. The pots were filled with a Zeandale silt loam (Coarse-silty, mixed, super active, calcareous, mesic Typic Udifluvents) to simulate field soil conditions. Soil bulk density was 1.14 g cm^{-3}. The drainage holes in the bottoms of each container were taped to ensure the soil did not wash out during the establishment phase of the study. The sedum, dianthus, and creeping Jenny were purchased from a local nursey and the remaining plants were propagated or transplanted from around the Throckmorton Plant Science Center and Rocky Ford Turfgrass Research Center in Manhattan, KS.

Pots were established in January or February and the establishment periods of all plants for both experiment runs were 101 and 104 d for Run A and Run B, respectively. To promote growth, supplemental light was provided for both studies' establishment periods until daily sunlight reached 12 h day^{-1} on 9 Apr. 2024. Measurements of relative humidity and air temperature were taken every minute and averaged over an hour continuously using a HOBO Data Logger (U23 Pro v2, Onset Corporation, Bourne MA). Average daily minimum and maximum air temperature for the establishment of Run A were 15.8°C and 21.7°C, respectively. The establishment during Run B showed slightly higher minimum and maximum daily temperatures, 19.8°C and 23.3°C, respectively. The plants were well watered during the establishment period and fertilized weekly with a 20-10-20 soluble fertilizer at a rate of 200 ppm N. The turfgrass species were mowed weekly at a 7.5 cm height to simulate a home lawn height of cut. The ground cover species were pruned to the outside edge of the 25 cm diam. x 29.5 cm height container as needed during the establishment period.

The plant species were treated with pesticides/biocontrols throughout the establishment period to control aphids, white fly, spider mites, thrips, and scale. The applications included; spinosad [mixture of (spinosyn A, R=H) and (spinosyn D, R=CH3)] at 2 oz·gal^{-1} on 12 Jan. 2024; S-Kinoprene (2-propynyl-(2E,4E,7S)-3,7,1 1-trimethyl-2-4-dodecadienoate) at a rate of 32 fl oz·100 gal^{-1} on 15 Feb. 2024 and 14 Mar. 2024; Pyrifluquinazon2(1H)-Quinazolinone,1-acetyl-3,4-dihydro-3-[(3-pyridinylmethyl) amino]-6-[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]- at a rate of 3.2 fl oz·100 gal^{-1} on 15 Feb. 2024; etoxazole at a rate of 16 oz· 100 gal^{-1} on 15 Feb. 2024; cyflumetofen: (2-methoxyethyl(RS)-2-(4-tert-butylphenyl)-2-cyano-3-oxo-3- (α,α,α-trifluoro-o-tolyl)propionate) at a rate of 13.7 fl oz·100 gal^{-1} on 14 Mar. 2024. The plants had biocontrol releases of *amblysieus cucumeris* on 25 Jan. 2024.

After establishment, the containers were arranged in the greenhouse in a randomized complete block design with three replications. Irrigation ceased on 14 Apr, 2024, and 26 May, 2024 for Run A and B, respectively. The plants received no water from the start of the study until each respective plant reached a visual quality rating of one (1=dead/dormant, 6=minimally acceptable, and 9=highest visual quality) depending on plant density, uniformity, and plant color. This is the standard scale for evaluating turfgrass in National Turfgrass Evaluation Program (NTEP) trials (Morris & Shearman, 2000) and was adapted to the ornamentals in this study. Once a visual quality of one was recorded, the respective container was then watered for the following sixty days to evaluate green cover recovery, if any. During this 60-day recovery period, visual percent green cover was collected up to three times per week and was the only data collected.

Supplemental light was not added for Run A but was used in Run B when daily light intervals were less than 12 h d^{-1} on 25 Sept. 2024. Daily maximum PAR ranged from 101.2 to 1313.7 µmol $m^{-2}s^{-1}$ during Run A and 106.2 to 1026.2 µmol $m^{-2}s^{-1}$ during Run B. Daily minimum and maximum temperatures were 19.9°C /26.4°C (Run A) and 20.9°C/26.2°C (Run B).

Data Collected

Visual quality, pot weight, and volumetric water content (θ_v) were measured three times per week. When plants reached a visual quality rating of one (1=dead/dormant, 6=minimally acceptable, and 9=highest visual quality) depending on plant density, uniformity, and plant color, irrigation resumed to attempt recovery. Container water loss was measured by weighing containers to the nearest gram using a balance (CD-11, Ohaus Corporation, Florham Park, NJ). Volumetric soil water content (θ_v) was measured using 20 cm probes with time domain reflectometry with one measurement per pot (Fieldscout TDR 250, Spectrum Technologies Inc., Aurora, IL). Measurements of container water loss and θ_v were taken until the plant rating declined to a visual quality rating of one.

Stomatal conductance (g_s) and leaf water potential (Ψ_{Leaf}) were measured once per week throughout the dry down period of both studies. Stomatal conductance (g_s) was measured weekly when sky conditions were clear. Measurements were taken using a steady-state diffusion porometer, (SC-1, METER Group, Pullman, WA). The bottom side of one leaf was selected for the groundcovers with large enough leaves: Vinca and lambs ear. The smaller leaved groundcovers and turfgrasses, Sedum, Dianthus, Creeping Jenny, Phlox, Tall fescue, Kentucky bluegrass, and Buffalograss, needed three to five leaf blades to cover the entire chamber orifice of the SC-1 to get an accurate reading. Only one measurement was taken per container each week.

Leaf water potential (Ψ_{Leaf}) measurements were taken weekly using a dewpoint hygrometer (WP4-T, METER Group, Pullman, WA). Leaf cuttings were taken similar to the SC-1. Plant leaf material was removed to cover the bottom of the sample cup (5 cm diameter) of the WP4-T. Plant leaf cuttings were stored temporarily in sealed bags prior to measurements to decrease the amount of water loss until the leaf was measured with the WP4-T.

During the recovery period, the percent green cover was visually rated up to three times per week using a 0% to 100% scale (0%=no green cover and 100%=full recovery). The percentage of the pot covered with any green plant material, not including weeds or other contaminants, was estimated. During the recovery period, plants were watered weekly to simulate normal growing conditions.

Data Analysis

Studies A and B were analyzed separately due to different environmental conditions throughout the dry downs. Species averages for visual quality, water loss, θ_v, Ψ_{Leaf}, and stomatal conductance (g_s) were analyzed for differences among species using the general linear model

(GLM) procedure in SAS 9.04.01 (2022) as randomized complete block designs. The means of each species were separated using Fisher's Protected Least Significant Difference (LSD) test at $P=0.05$.

Results and Discussion

Drought Ratings

Sedum took longer to reach a visual quality of one compared to all other species (143 and 170 until a visual quality of one) for Run A and B, respectively (Figure 2.1). Lambs ear was the second longest species averaging 105 and 80 until visual quality of one for Run A and B. The remaining species did not perform as well as sedum and lambs ear, ranging from 29 to 59 days to decline to a visual quality rating of one for both Run A and B.

During the dry down period of Run A, the visual quality rating of all species except creeping Jenny and lambs ear remained at six or greater through the first three weeks (Figure 2.2). Six weeks into the dry down, only two species' averages remained above a visual quality of six, buffalograss (8) and sedum (7.5). Buffalograss, being a warm-season grass, is able to maintain turgor pressure as soils dry down and have a lower ET rate (Qian & Fry, 1997). Sedum, a CAM plant, is able to keep its leaf water potential unchanged through drought stress, so it can remain at a higher visual quality longer than the cool-season counterparts (Sayed et al., 1994). Dianthus was the next highest visual quality at five, while the rest were at three or under during the sixth week of the drought. At week three for Run B, all species rated greater than a visual quality of seven performed better than Run A to this point in the dry down. At week six, only sedum was rated higher than a visual quality of seven. Buffalograss and lambs ear had visual quality ratings of three, while the remaining species rated below a two visual quality rating. A potential reason for the variation from Run A to Run B is the increases in vapor pressure deficit

(VPD) at different times within each study. At the end of week 1, the VPD in Run A reached 1.4 kPa explaining the variation in visual quality ratings among plants in week three. Run B reached a high VPD (2.2 kPa) in week five resulting in lower visual quality ratings for week six (Figure 2.3). The higher the VPD the more the plants transpire (Grossiord et al., 2020), which may have led to Run B's species reaching a visual quality of one faster.

Following the dry down period, the species experienced normal irrigation for 60 days (once or twice per week). Run A had three species recover substantially, buffalograss (93%), Tall fescue (57%), and sedum (48%) (Figure 2.4). Tall fescue's ability to recover is similar to previous drought research conducted (Karcher et al., 2008). Creeping Jenny and phlox had approximately 15% each, while the remaining plants had no percent green cover throughout the 60-day recovery period. Run B had different results, Tall fescue had the most recovery with 33%, followed by buffalograss (22%), creeping Jenny (13%), and vinca (10%). In a previous study, vinca was able to recover to 35% after deficit irrigation (J. Domenghini et al., 2013). Kentucky bluegrass, sedum, and dianthus had less recovery ending with 7%, 1%, and 0.01% green cover, respectively, at the end of the recovery period. It is likely the higher VPD during Run B's recovery phase led to the poor regrowth of multiple species.

Container Water Loss and Volumetric Water Content

Container water loss showed the difference in pot weight between the nine species. Run A had less water loss overall compared to Run B through the first ten days after irrigation ceased. Near the beginning of Run A, Tall fescue and Kentucky bluegra*ss* had the most water loss ten days into the dry down with 2789 mL and 2554 mL of water loss (

Figure 2.5). The remaining plants' water loss on day ten ranged from 1893 mL to 1005 mL. For Run B, Kentucky bluegrass, tall fescue, and lambs ear lost the most water through day ten with 3381 mL, 3139 mL, and 2870 mL, respectively. Vinca (2146 mL) and creeping Jenny (1917 mL) had the next most water loss, while the remaining species (phlox, buffalograss, and dianthus) lost the least amount of water ten days into the dry down. The weight of the pots, however, did not account for the growth of the plants as the study progressed, so we assume the plant growth as constant through the dry down.

Similar to container water loss, decrease in soil volumetric water content (θ_v) was drastically different from Run A to Run B ten days into the dry down. Average θ_v for all species at the start of the drydown was 41.3% and 58.6% for Run A and Run B, respectively. The species in Run A with the minimum decrease in (θ_v) were buffalograss (8%), sedum (12%), and phlox (12%) (Figure 2.6). Species which decreased the most from their starting θ_v included, tall fescue (28%), Kentucky bluegrass (22%), creeping Jenny (22%), and vinca (20%). Run B had a greater decline in θ_v, with buffalograss and dianthus losing 13% and 16%, respectively. Species with the greatest decrease in (θ_v) included lambs ear (45%), tall fescue (44%), and Kentucky bluegrass (44%).

Stomatal Conductance and Leaf Water Potential

The change in stomatal conductance for each species from week one through week five is shown in Figure 2.7. Each species started at different values (mmol m^{-2} s^{-2}) in week one, and Figure 2.7 illustrates the change from each species' individual starting point. Stomatal conductance decreased for both studies, although Run B had a greater overall decrease. In Run A buffalograss had a slight increase (9.5 mmol m^{-2} s^{-2}) in stomatal conductance five weeks into the dry down. The remaining species in Run A had a greater decrease in stomatal conductance ranging from 191.4 to 429.9 mmol m^{-2} s^{-2}. Run B had four species with the least amount of decrease in stomatal conductance five weeks into the dry down, dianthus, buffalograss, phlox, and sedum with 158.8, 179.5, 216.6, and 216.7 mmol m^{-2} s^{-2} loss, respectively (Figure 2.7). Vinca had a decrease of 504.6 mmol m^{-2} s^{-2} and lambs ear had a decrease of 606.7 mmol · m^{-2} · s^{-2} five weeks into the dry down. The remaining species, Kentucky bluegrass, tall fescue, and creeping Jenny had already reached a plant visual quality rating of one, so they did not have any stomatal conductance readings at five weeks.

The absolute value of leaf water potential (Ψ_{leaf}) in kilopascals (kPa) is shown on a logarithmic scale (log base 10) to show the decrease during weeks two, three, and five (Figure 2.8). One-unit increase means a tenfold reduction, two-unit increase means a 100-fold reduction in Ψ_{leaf}, and so on. Run A had all nine species remaining in the dry down portion of the Run. At week 5, with sedum and buffalograss having the least decrease in Ψ_{leaf} with 395 kPa and 857 kPa, respectively. Vinca had the greatest decrease in Ψ_{leaf} at week five with 72,220 kPa. The remaining decreases in the study for the other six species ranged from 16,327 kPa to 44,183 kPa. A couple species in Run A had no decrease in Ψ_{leaf} from week one to week two, Kentucky bluegrass and dianthus, while buffalograss did not decrease until after week three. This indicates these species were able to maintain their leaf water potential and be unaffected by the drought conditions for longer than the other six species. Buffalograss has high osmotic adjustment as soil dries down (Qian & Fry, 1997), which assisted in keeping Ψ_{leaf} unchanged into week three.

At week five Run B showed greater decrease than Run A and only six species remained in the dry down. Sedum and buffalograss had the least water potential decrease with 470 kPa, 410 kPa and 1,306,810 kPa, respectively. These greater decreases in water potential in Run B are likely caused by the increase in VPD (2.2 kPa) that occurred in week five (Figure 2.3). Species that remained in the run and showed more of a decrease include vinca (4,388,950 kPa), phlox (4,399,510 kPa), lambs ear (5,024,820 kPa), and dianthus (5,401,270 kPa), with no significant difference from one another. Tall fescue, creeping Jenny, and Kentucky bluegrass which declined to a visual quality of one (ending the dry down and beginning the recovery phase where measurements were no longer collected) prior to week five during the study period, were not able to endure the intense drought conditions. Similar to Run A, a few species in Run B were able to maintain their Ψ_{leaf} for the first few weeks of the study. Sedum [(week four) not shown in Figure 2.8], buffalograss (week three), tall fescue (week two), and Kentucky bluegrass (week two). Sedum was able to maintain Ψ_{leaf}, as it uses the CAM pathway and sustains Ψ_{leaf} throughout drought conditions (Sayed et al., 1994). Interestingly, tall fescue and Kentucky bluegrass were able to maintain their Ψ_{leaf} into week two, however, they were not able to maintain their visual quality rating as well as most of the other species, and they were in the 60-d recovery period by week five.

Conclusions

Results of the study show sedum survived the longest without supplemental water, maintained its visual quality rating, and was also able to recover. Stomatal conductance and Ψ_{leaf} measurements for sedum showed the least change from the start of the study. Overall, sedum would be an ideal alternative to turfgrass lawns in non-recreational areas of a landscape. Buffalograss was similar to sedum with visual quality, however, buffalograss maintained higher volumetric water content ten days into the dry down, and had greater recovery after irrigation resumed. Stomatal conductance remained high for buffalograss and had similar results in Ψ_{leaf} compared to sedum.

A few species had higher measurement values in one or two of the parameters measured, which may assist the species to survive drought conditions in the Midwest, but extra management/irrigation practices may be necessary. For both Run A and B, tall fescue had a high recovery rate but had poor water retention in both container water loss and θ_v. Kentucky bluegrass showed some recovery and also had poor water retention. Results indicate creeping Jenny and vinca showed low recovery rates and decent water retention. Vinca also had a large decrease in Ψ_{leaf} and stomatal conductance, which indicates it is not as drought tolerant. Dianthus and phlox had no recovery and were located in the middle of all other measurements gathered. Lastly, lambs ear showed the second longest days to reach a visual quality of one but performed extremely poor in all other areas (container water loss, θ_v, Ψ_{leaf}, and g_s) indicating it is not an ideal plant for drought landscapes.

Field research may be necessary to validate the drought tolerance of the nine species evaluated in this greenhouse study to draw more concrete conclusions.

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Figures

Figure 2.1 The number of days to decrease to a visual quality of one for all nine landscape species during dry down Run A (dry down began 15 Apr. 2024) and Run B (dry down began 27 May 2024). Means given the same letter within each run are not significantly different from one another according to Fisher's LSD test (α=0.05)

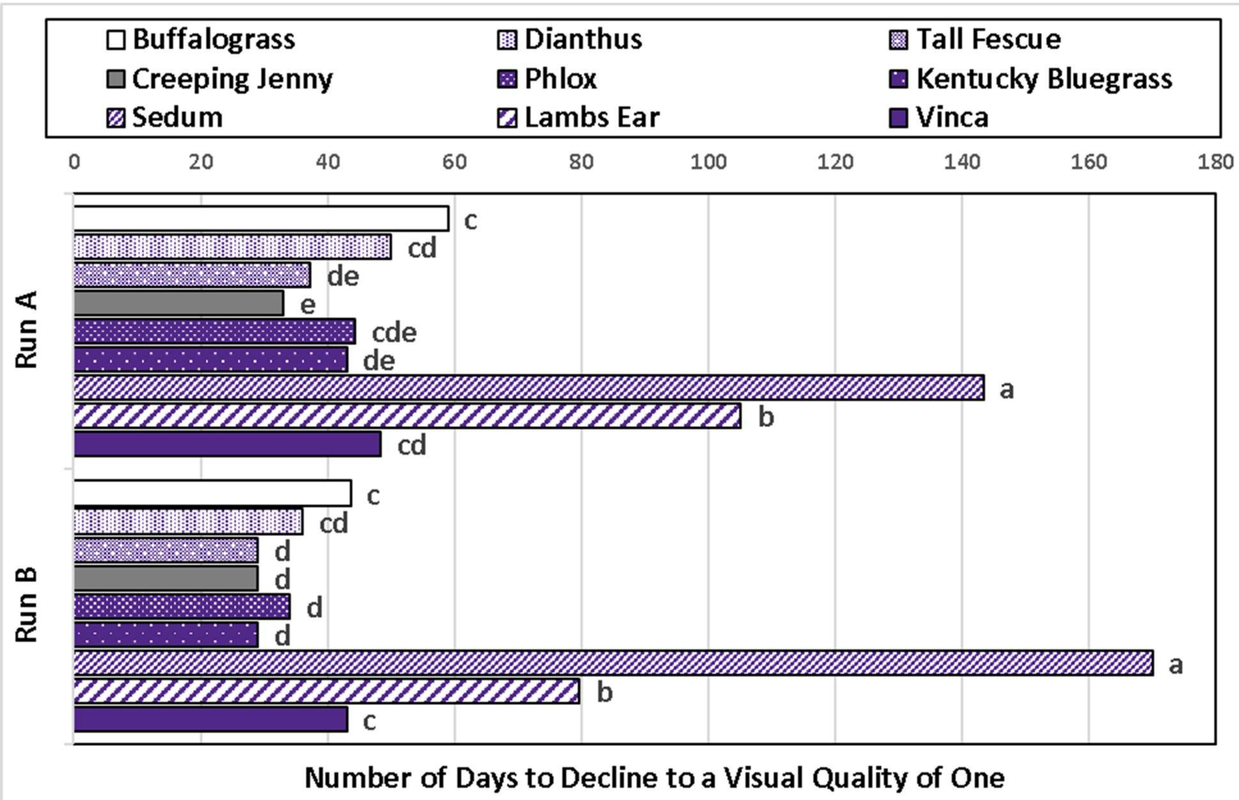


Figure 2.2 Mean plant visual quality ratings for all nine species for weeks 3 and 6 of Run A (dry down began 15 Apr. 2024) and Run B (dry down began 27 May 2024). Means given the same letter within each week of each study are not significantly different from one another according to Fisher's LSD test (α=0.05).

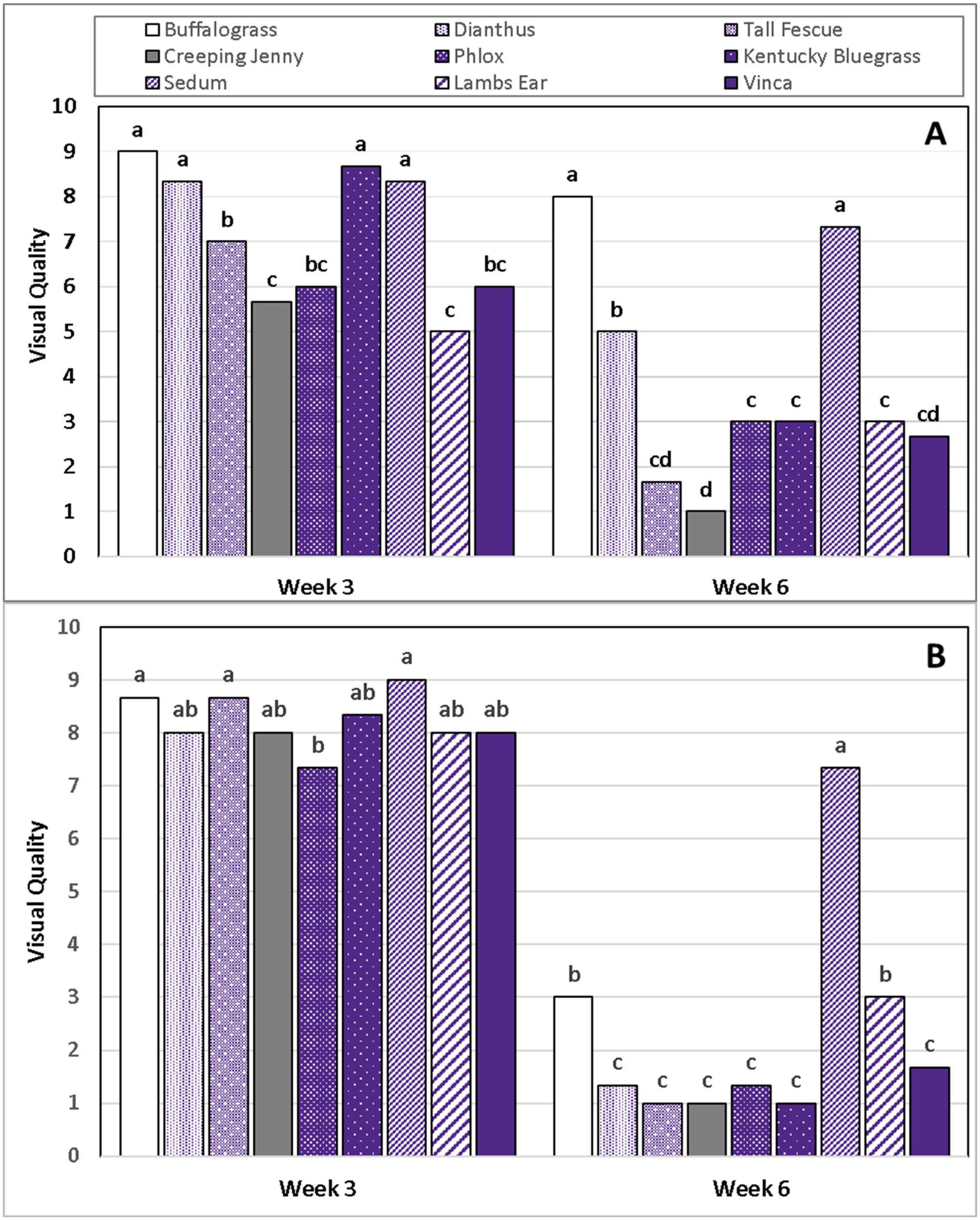


Figure 2.3 Trend in daily daytime vapor pressure deficit (VPD) values through Runs A and B. Air temperature (°C) and percent relative humidity values from the U23 Pro v2 HOBO data logger were used to find saturation vapor pressure (e_s), atmospheric vapor pressure (e), and VPD values.

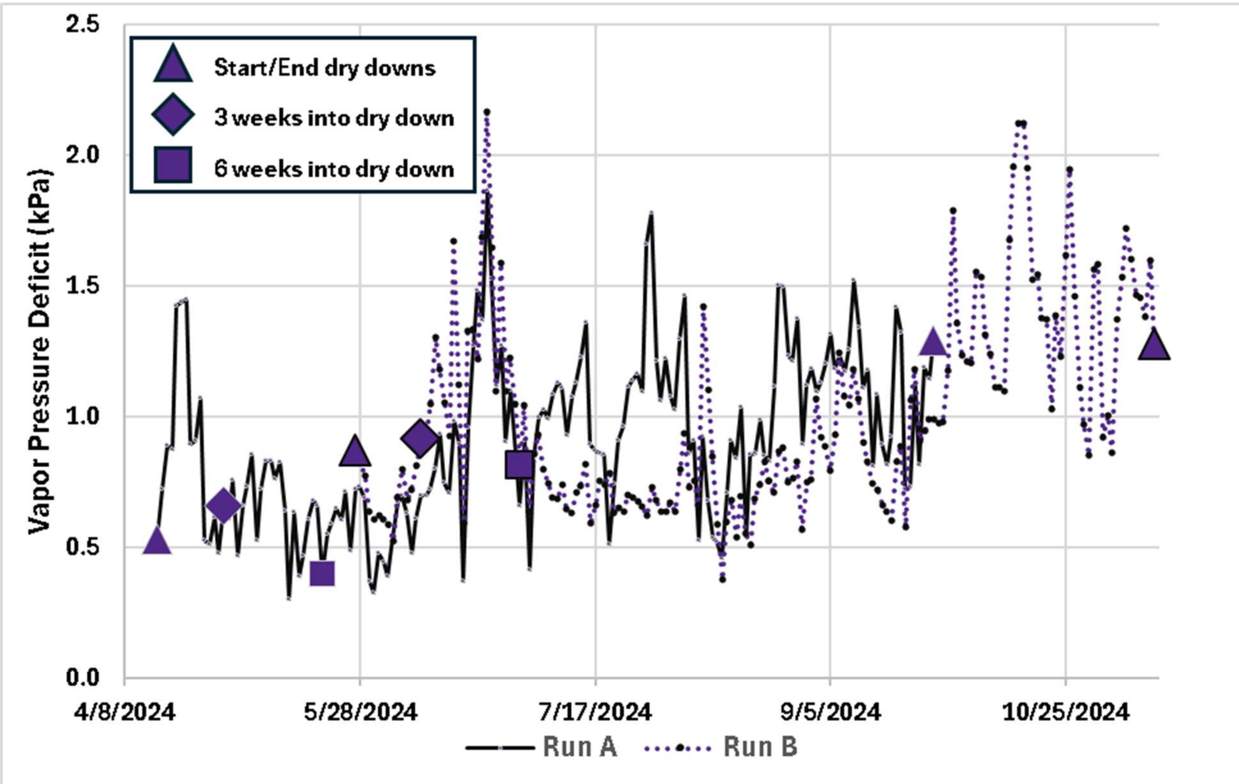


Figure 2.4 Average percent green cover for each species during 60-day recovery for Run A and Run B (recovery start date depended on each species decline rate). Means given the same letter within each day are not significantly different from one another according to Fisher's LSD test (α=0.05).

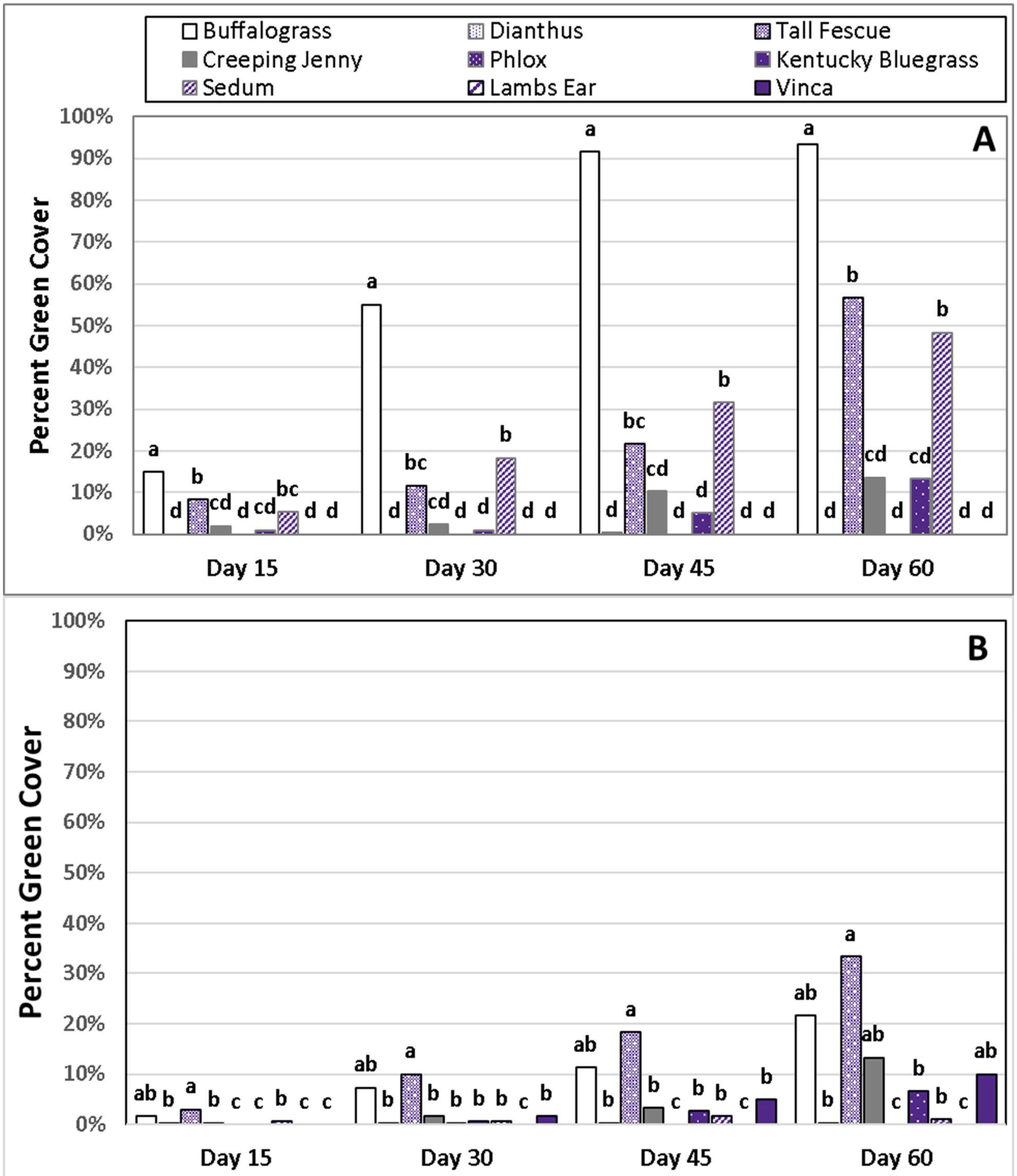
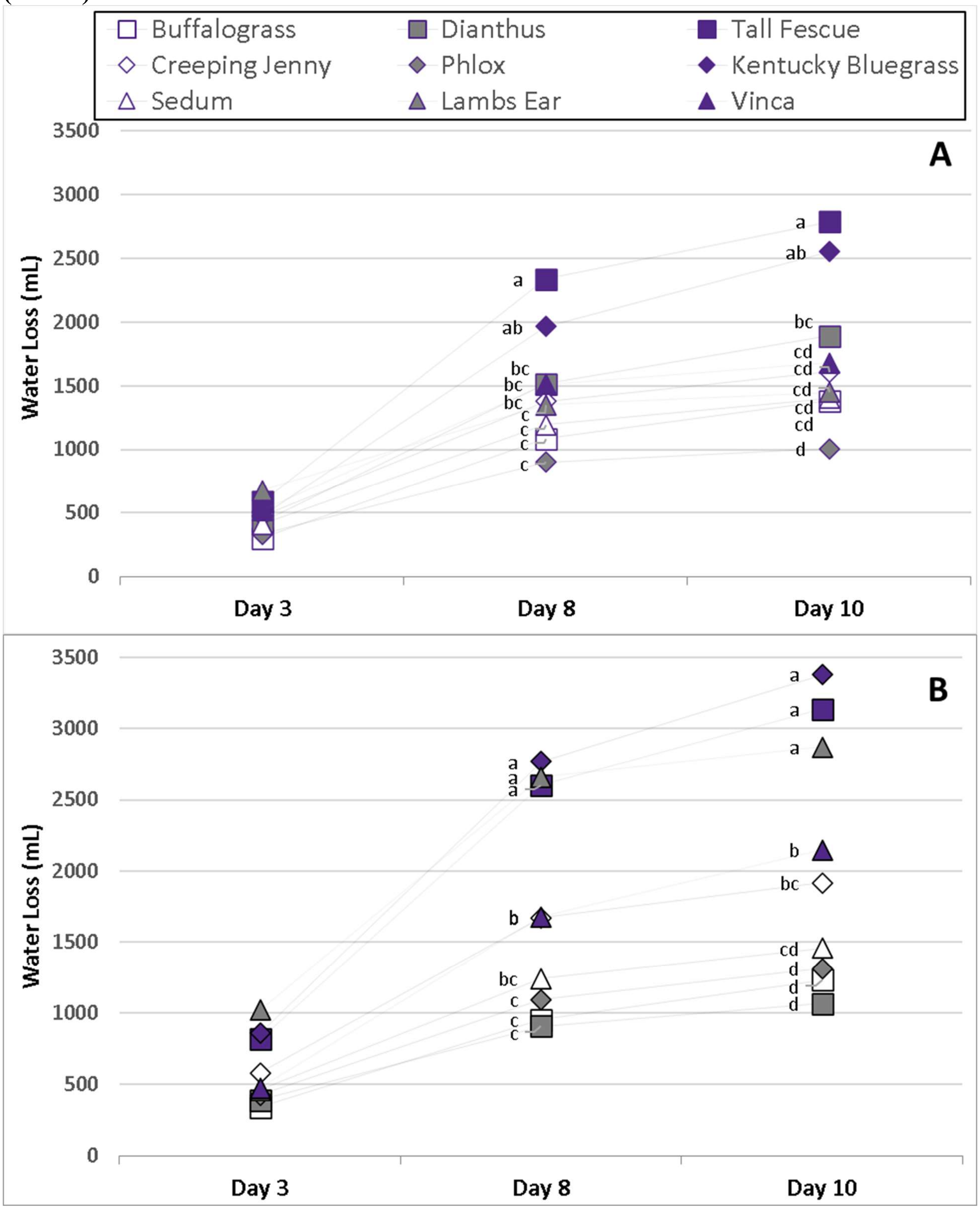


Figure 2.5 Mean water loss (mL) through the first ten days of Run A (dry down began 15 Apr. 2024) and Run B (dry down began 27 May 2024). Means given the same letter within each day are not significantly different from one another according to Fisher's LSD test (α=0.05).



B

Figure 2.6 Volumetric water content [cm^3 cm^{-3} (θ_v)] loss from day one value through the first ten days in Run A (dry down began 15 Apr 2024) and Run B (dry down began 27 May 2024). Means given the same letter within each day are not significantly different from one another according to Fisher's LSD test (α=0.05).

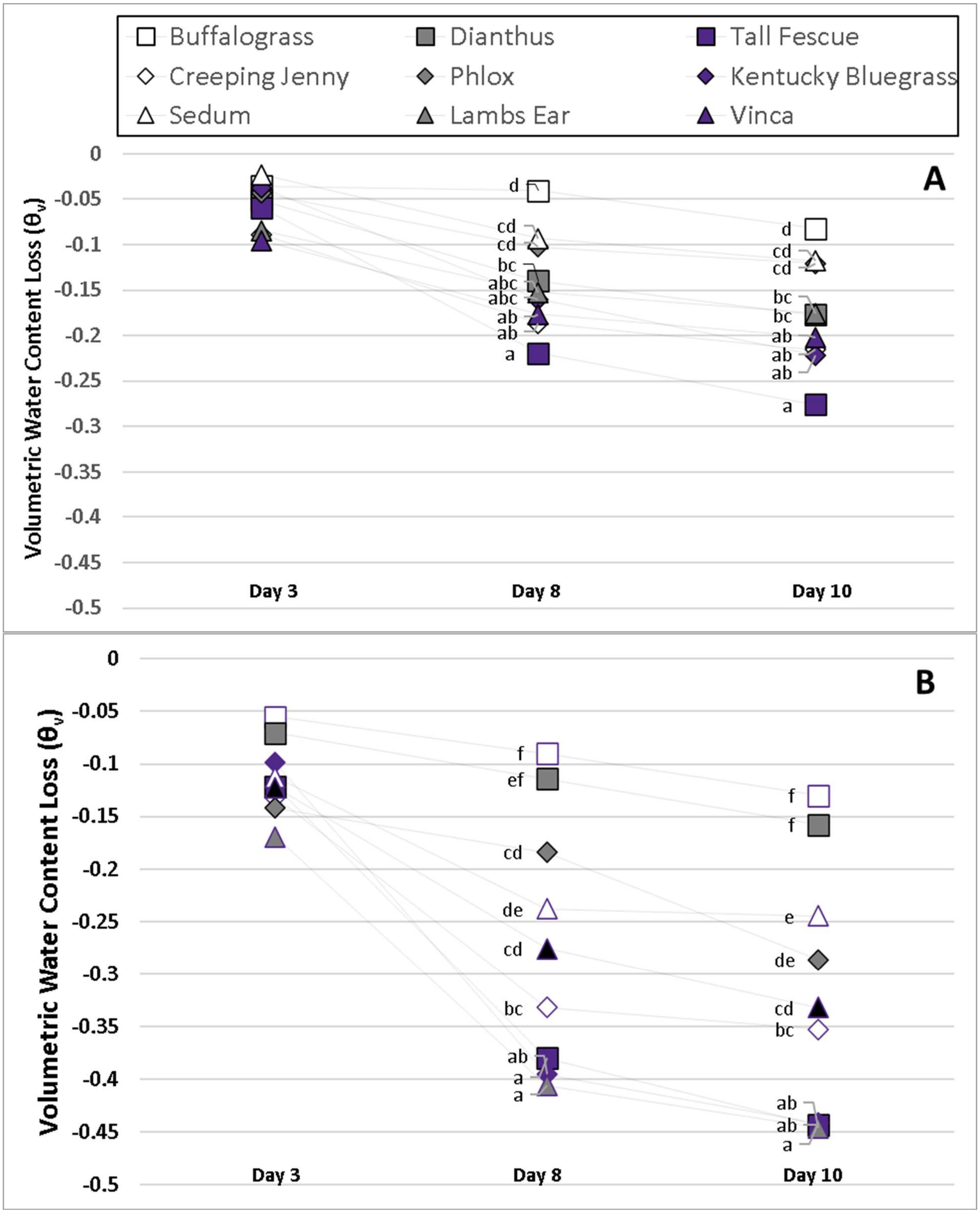


Figure 2.7 Average change in stomatal conductance from starting value on day one (mmol m^{-2} s^{-2}) through the first five weeks during Run A (dry down began 15 Apr. 2024) and Run B (dry down began 27 May 2024). Means given the same letter within each week are not significantly different from one another according to Fisher's LSD test (α=0.05).

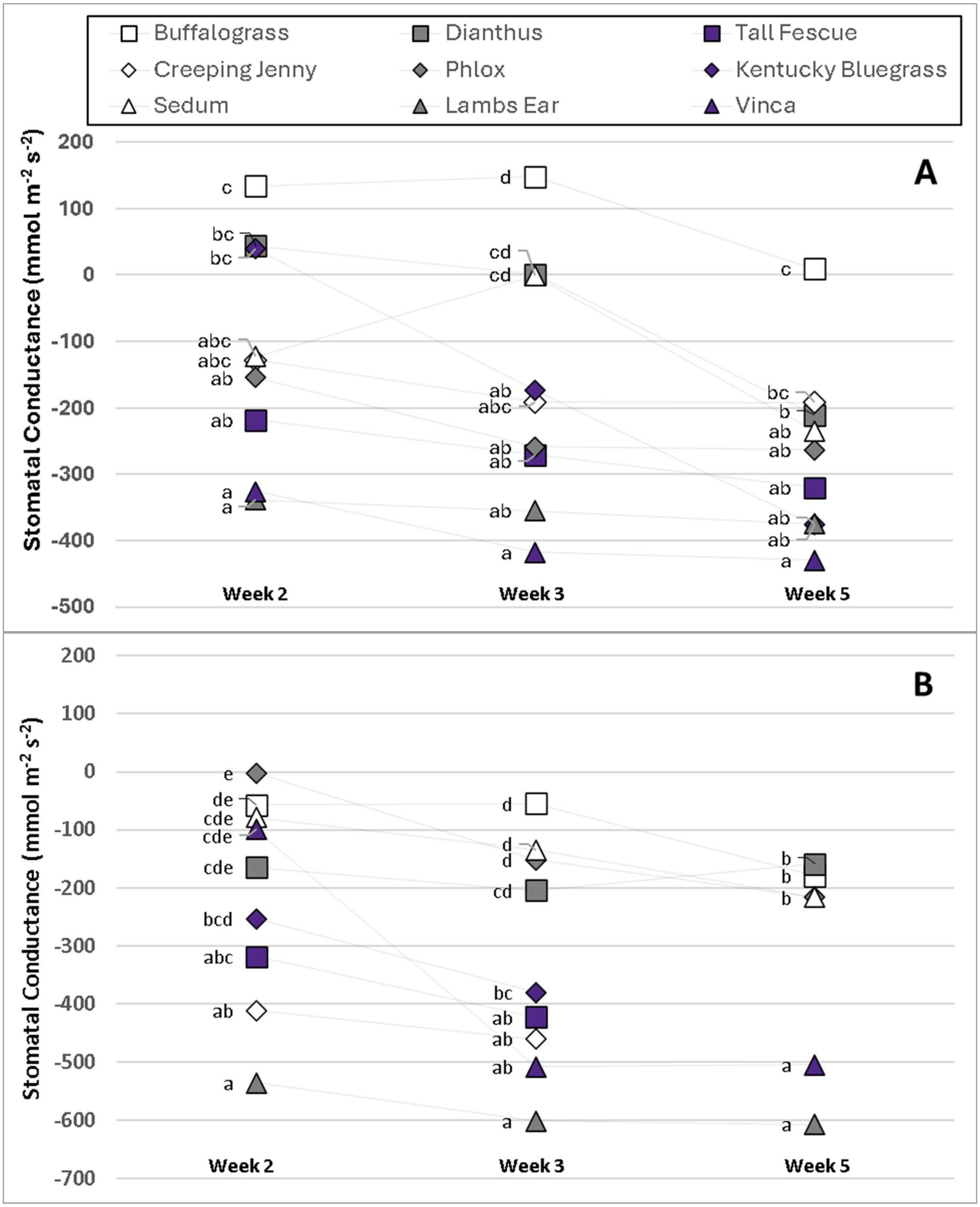


Figure 2.8 Change in leaf water potential [log |kPa| (Ψ_{leaf})] from day one values through the first five weeks during Run A (dry down began 15 Apr. 2024) and Run B (dry down began 27 May 2024). Means given the same letter within each week are not significantly different from one another according to Fisher's LSD test (α=0.05).