Establishing tall fescue using drip irrigation and protective covers

by

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Abstract

Subsurface drip irrigation (SDI) may save water but the effectiveness of SDI in establishing turfgrass from seed across different soil types and climates requires further investigation. Research is even more limited regarding the establishment of cool-season turfgrasses using turfgrass protective covers in combination with SDI. Two research projects were conducted at the Rocky Ford Turfgrass Research Center, Manhattan, KS. In both, turfgrass establishment was evaluated with measurements of turfgrass green cover (GC), visual turfgrass quality (TQ), and ground and drone-based normalized difference vegetation index (NDVI). The first project (Chapter 1) investigated effects of different frequencies and methods of irrigation, and two cultivation methods on the establishment of a cool-season turfgrass, tall fescue [*Festuca arundinacea* (Schreb.)], from seed in the fall of 2019 and 2020. Turfgrass established faster in SDI than the other methods including overhead sprinklers and an above-ground drip irrigation system. Overall, the best establishment among irrigation methods was with SDI that applied water 2x per day vs. 3x or 1x per day. Cultivation had no effect on establishment and no damage occurred to SDI buried at a depth of 15.24 cm when plots were core aerified with 7.62 cm hollow irrigation tines. The second study (Chapter 2) was repeated sequentially in the spring of 2020 and focused on the use of different irrigation methods in conjunction with protective turfgrass covers consisting of polyester mesh, a straw blanket, and no cover (control). Both cover types improved establishment compared to no cover, generally in the order of, from highest to lowest, polyester mesh > straw blanket > no cover in both trials. Establishment of tall fescue with SDI was similar to overhead irrigation and aboveground drip irrigation in the spring study. Soil temperature was ~7 ºC higher under polyester mesh turf covers than under straw blanket and in no cover plots. Polyester covers mitigated low temperature extremes, but both cover types prevented erosion

early in the study, resulting in better establishment in covered plots, especially in polyester mesh plots. Overall, results demonstrated that SDI established tall fescue from seed similarly to or better than overhead sprinklers when applying 150% reference evapotranspiration 2x per day, and that covers improved spring establishment.

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Dedication

This thesis is dedicated to my supportive and loving parents. Without their help throughout my life this would not have been possible.

Chapter 1 - Establishing Tall Fescue from Seed Using Different Irrigation Application and Cultivation Methods

Abstract

Subsurface drip irrigation (SDI) may save water but the effectiveness of SDI in establishing turfgrass from seed across different soil types and climates requires further investigation. This two-year study was conducted in fine-textured soils in the transition zone of the US near Manhattan, KS. Our objectives were to investigate the establishment of a cool-season turfgrass, tall fescue [*Festuca arundinacea* (Schreb.)], from seed using: 1) SDI, aboveground drip irrigation (AGD), and overhead sprinkler irrigation (OH; control); 2) three SDI frequencies; and 3) core aeration and verticutting cultivation methods. Establishment was evaluated with green cover (GC), visual turfgrass quality (TQ), and normalized difference vegetation index (NDVI). Seeded turfgrass established faster with SDI than with AGD or OH. By the end of the first month after seeding, GC and NDVI were up to 25% and 15% greater, respectively, in SDI than AGD and OH. Among SDI irrigation frequencies, establishment was fastest when water was applied 2x versus 3x or 1x per day. Cultivation method did not affect establishment in this study, indicating core aeration and verticutting are appropriate for establishing turfgrass from seed with SDI as long as relative depths of cultivation and dripline placement are considered to avoid damage to SDI. Establishment was slower with AGD than SDI, but AGD was similar to OH. Results indicate that tall fescue turfgrass can be successfully established from seed with SDI in fine-textured soils in a transition zone climate.

Introduction

The conventional method of establishing turfgrass from seed is with some type of overhead irrigation sprinkler system (Niazi *et al.*, 2018). This method of water delivery may be inefficient because of water loss through evaporation, wind drift or surface runoff (Leinauer and Devitt, 2013). Surface runoff is typically the result of excessive runtimes and lack of implementing cycle and soak application methodology, particularly in fine-textured, clay soils because their infiltration rates are lower than that of coarse, sandy soils (Huang *et al.,* 2006). Poor distribution uniformities from wind or lack of irrigation system audits may also contribute to inefficient water delivery.

An increasingly popular method of maintaining turfgrass is subsurface drip irrigation (SDI), which is improving with technology (Leinauer and Devitt, 2013; Reich, 2014). Subsurface drip irrigation directly applies water to the soil/root interface using pressure-compensating driplines buried in the soil, resulting in less water loss through evaporation, wind drift or run-off than with overhead sprinkler methods (Schiavon et al., 2014). Serena et al. (2016) estimated water savings of up to 40% when using SDI in warm season turfgrasses, suggesting SDI is an efficient irrigation system. Golf course tees irrigated with overhead irrigation used three to five times more water than tees irrigated with SDI, primarily because of overspray into the surrounding areas (Leinauer et al., 2018).

To date, most SDI research in turfgrass has been in coarse-textured soils in the semi-arid, southwestern U.S. A number of studies in that region have indicated that turfgrass quality in cool- and warm-season species was similar between plots maintained with SDI and traditional overhead sprinkler irrigation (Leinauer et al., 2010; Leinauer et al., 2018; Schiavon et al., 2015; Serena et al., 2014; Serena et al., 2016; and Suarez-Rey et al. 2000). Even when saline water was used, turfgrass quality was generally similar between SDI and overhead sprinkler irrigation in both warm- and cool-season turfgrass species (Sevostianova et al., 2011a, 2011b; Schiavon et al., 2013; Schiavon et al., 2014).

If SDI is to be installed in lieu of overhead sprinkler systems, one important consideration is to evaluate the effectiveness of using SDI in the establishment of turfgrass from seed, but only a few studies have investigated this. Propagated bermudagrass (*Cynodon dactylon* L.) was successfully established using SDI, reaching >90% green cover by the end of the growing season, although establishment was slower with SDI than with overhead sprinkler irrigation (Serena et al., 2014). Bermudagrass and seashore paspalum (*Paspalum vaginatum* L.) were successfully established from seed using SDI in New Mexico and California, although establishment was also slower with SDI than overhead irrigation in both locations, and green cover only reached 75% in SDI in New Mexico compared with full cover in California by the end of the growing season (Schiavon et al., 2015). Similarly, tall fescue and Kentucky bluegrass (*Poa pratensis* L.) were successfully established from seed using SDI in New Mexico although establishment was slower and green cover was less than with overhead sprinkler irrigation at the end of the growing season (Schiavon et al., 2013).

As mentioned above, most SDI research in turfgrass has been conducted in sandy loam soils, and has indicated that turf can successfully be established and maintained using SDI. In sand-based soils, less upward capillary movement of water compared to fine-textured soils may restrict water availability at the surface for the establishment of seed if SDI zones are not designed correctly (Turgeon, 2008; Salim, 2016). Therefore, it may be expected that establishment of turfgrass grown in fine-textured soils would also be successful. Nevertheless, research using SDI in fine-textured (silt- or clay-based) soils is lacking. The frequency of irrigation may possibly be reduced in fine-textured soils because of their higher water-holding capacity compared with coarse-textured soils. However, the time required for water to move laterally and thus, for the wetting fronts to converge between driplines may differ between fine- and coarse-textured soils, which could impact optimum irrigation frequencies. Research is needed to evaluate frequency of irrigation using SDI in fine-textured soils when establishing seeded turfgrass.

Cultivation technique (e.g., core aeration, verticutting) is an important consideration when using SDI in turfgrass. For example, cultivation could damage the SDI system if cultivation is deep enough to reach the driplines (Leinauer and Devitt, 2013). Cultivation method also may affect establishment of seeded turfgrass when using SDI. Specifically, differences in depths of cultivation, spacing between tines or blades on equipment, etc., could affect germination by altering the microenvironment (e.g., moisture and temperature) surrounding the seeds and emerging seedlings. However, to our knowledge there has been no research regarding the effects of cultivation on turfgrass establishment when using SDI.

Aboveground drip irrigation has been suggested as a portable system to enhance the establishment of turfgrass along roadsides (Eric Watkins, personal communication, 10 July 2019). Friell and Watkins (2020) noted that pre-and post-establishment irrigation practices on roadside turfgrass is an important consideration in its establishment and maintenance, but little research has been conducted to evaluate the use of aboveground drip irrigation in the establishment of turfgrass.

Therefore, the objectives of this research were to investigate establishment of seeded tall fescue using: 1) SDI and aboveground drip irrigation (AGD); 2) different SDI runtimes; and 3) two cultivation methods. Specifically, our goal was to determine if SDI or AGD could effectively establish cool-season turf from seed comparable to conventional overhead irrigation in fine-textured soils. Tall fescue was selected for this study because it is the most widely used turfgrass in residential lawns in some areas of the transition zone (Bremer et al., 2012), is popular on US golf courses (Gelernter et al., 2017)**,** and is well adapted to roadside conditions (Friell and Watkins, 2020).

Materials and Methods

Maintenance

Research was conducted at Rocky Ford Turfgrass Research Center, Manhattan, Kansas (39º13’53’’N, 96º34’51’’W), from 1 Oct. to 1 Nov. 2019 and 24 Sept. to 26 Oct. 2020. The soil was a Chase silty clay loam (fine, smectitic, mesic Aquertic Argiudoll). The experiment was arranged in a split-plot randomized complete block design with irrigation treatments applied to whole plots and cultivation treatments applied to split-plots within whole plots. Five irrigation treatments were each represented by a single irrigation zone (6.10 by 12.19 m), with each zone divided into four whole plots (3.05 by 6.10 m). Within each whole plot, two cultivation treatments were randomly applied to subplots (3.05 m by 3.05 m) for a total of 40 subplots (eight in each irrigation zone) in the entire study. All irrigation zones in the study were adjacent to each other.

Glyphosate (Glyphomate 41, PBI/ Gordon Corporation)((N-(phosphonomethyl))glycine) in the form of isopropylamine salt) was applied on 13 and 27 Aug. 2019, at a rate of 18.31 kg a.i. ha^{-1} to an existing sward of ‘Cody’ buffalograss. A third spot-spray application was made in select areas where buffalograss was not completely killed on 10 Sept. 2019, three weeks prior to starting the study in the first year. The dead buffalograss sod was then removed, leaving the soil surface exposed for cultivation and seeding.

Tall fescue was seeded to the study area on 1 Oct. in 2019 and 24 Sept. in 2020 at a rate of 391 kg ha^{-1}, using a shaker bottle in multiple directions and incorporated using a leaf rake to ensure good seed-to-soil contact. The tall fescue seed blend included the cultivars ‘Copious’ (38.67% purity), ‘Reunion’ (38.56% purity), and ‘Starfire II’ (22.27% purity)(All Pro Transition Blend, Lesco Inc.). The study area was then covered with a 0.05 polyester mesh frost protection blanket (DeWitt Company) to prevent seed movement during potential heavy rain events. The cover was removed after approximately one week, on 6 Oct. in 2019 and 30 Sept. in 2020, after seedlings had emerged. The tall fescue was not mown during the study.

Two cultivation treatments were applied to the split plots including: 1) core aeration (Toro 588 ProCore aerifier, The Toro Company), and; 2) verticutting (Billy Goat power rake, Briggs & Stratton). Core aeration removed 1.27 cm diameter cores measuring approximately 7.62 cm deep and spaced 7.62 cm apart.

Irrigation treatments included subsurface and surface drip and traditional overhead sprinklers. Irrigation amounts on all plots was 150% evapotranspiration replacement applied three times per day (approximately 0800, 1300, and 1700 CST) with the exception of less frequent applications in two SDI treatments. Specific irrigation treatments included: 1) SDI, three times daily (SDI 3x); 2) SDI, two times daily (SDI 2x; ~0800 and 1700 CST); 3) SDI, once daily (SDI 1x; ~1300 CST); 4) surface (aboveground) drip (AGD), three times daily; and 5) traditional overhead sprinklers (OH)(I-20 gear-drive rotors, Hunter Industries) as the control treatment, three times daily. The dripline in both SDI and AGD was pressure-compensating dripline (Techline Dripline, Netafim) spaced 45.72 cm apart. Water was applied at a rate of 20.82 mL min^{-1}. Subsurface driplines were buried at 15.24 cm. Dripline specifications are decided based on soil type. Distribution uniformity for the overhead sprinkler zone was 75% prior to the trial in each year, as determined with catch-device audits.

Measurements

After the erosion-prevention covers were removed, data were collected weekly in 2019 and twice weekly in 2020 before the midday irrigation (1200 CST). Green cover (GC) was measured with digital images (Nikon D5000, Nikon Inc.) using a lighted camera box. Images were analyzed with SigmaScan Pro (ver. 5.0, SPSS Science Marketing Dept.) (Karcher and Richardson, 2005) with hue ratio set at 45/100 and saturation ratio at 0/100. Visual turf quality (TQ) was rated on a 1 to 9 scale (1 = poorest quality, 6 = minimally acceptable, and 9 = highest quality) according to color, texture, density, and uniformity (Morris and Shearman, 1999). Measurements of normalized difference vegetation index (NDVI) were obtained with a handheld device (RapidScan CS-45, Holland Scientific Inc.). Volumetric water content (VWC) was measured at a 0-7.6 cm soil depth and averaged from two random locations within each plot using time domain reflectometry (FieldScout TDR300 Soil Moisture Meter, Spectrum Technologies). Weather data were collected from an on-site weather station positioned in full sun within 100 m of the study area. Daily air and soil temperature (5 cm) and precipitation are presented in Figure 1.1.

Aerial measurements of NDVI were collected with small unmanned aircraft systems (sUAS) within 2.5 hours of local solar noon on one day in 2019 and three days in 2020. On 8 October 2019, which was a cloud-free day with calm winds, NDVI was measured according to the method of Hong et al. (2019) with the exception that flight height was increased to 35 m above ground level in this study. Briefly, this method included collection of ultra-high spatial resolution images (< 1-cm ground resolution) with a Canon PowerShot S100 camera modified to measure NDVI (MaxMax.com). The camera was mounted on a hexacopter (DJI S800 EVO) flown to achieve image overlap of at least 75%. In 2020, a new small unmanned system with a different sensor was acquired. Therefore, on 6, 13, and 19 Oct. 2020, images were collected with a Micasense RedEdge MX (AgEagle Sensor Systems Inc.) mounted on a fixed-wing drone (eBee X, senseFLY) flown at 75 m, which resulted in a resolution of 5 cm px^{-1}. The resulting JPEG images were then processed into orthomosaics using Agisoft Metashape Professional (v. 1.6.34 build 10732, Agisoft LLC). The image processing procedure involved the following steps: photo alignment using high accuracy and referenced pair preselection, building a dense cloud using a medium quality and aggressive depth filtering, building digital elevation model using the dense cloud source and extrapolated interpolation, building an orthomosaic using average blending mode, and exporting an orthophoto in TIF format. Treatment effects were analyzed from the orthophoto in ArcGIS (v. 10.8, ESRI Inc.) by extracting data from a square area that included the center 60% of each plot surface and using the zonal statistics as table feature.

Statistical Analysis

Data were analyzed using SAS On Demand for Academics Version 3.8 (SAS Institute Inc.). A generalized linear mixed model (GLIMMIX) was used to analyze data using a significance level of P=0.05. Data from three plots with severe erosion of seedbeds were omitted from the data analysis in 2019 (one each from AGD, OH, and SDI 1x). Precipitation totaled 71.4 mm during the first 5 days after seeding (DAS) (1 October 2019 – 5 October 2019).

Results and Discussion

Cultivation had no significant effects on GC, TQ, or NDVI during establishment (P=0.05). This is similar to results from research by others that indicated no differences between core aeration and verticutting in the establishment of turfgrasses, although those were not SDI studies (Hoyle et al., 2013; Carroll et al., 2020). Therefore, only irrigation effects are presented herein. Because there were significant irrigation-by-year interactions, data are presented separately by year.

No damage was observed to the SDI driplines from either cultivation method in this study. This indicates that core aeration and verticutting can be safely used in turfgrass irrigated with SDI under the conditions of this study. However, precautions should always be considered regarding relative depths of the driplines and cultivation.

Green Cover

In 2019, GC was consistently highest in the SDI treatments (Figure 1.2A). At 25 and 32 DAS, GC was significantly higher in all three SDI than in OH or AGD. The rate of increase in GC slowed after 25 DAS, especially in AGD and SDI treatments, probably because of dramatically lower temperatures during the last week of the study. For example, daily air temperature averaged 11.3 and 2.6 ºC in the week before and after 25 DAS, respectively, with subzero temperatures as low as -8.2 ºC on seven of the last eight nights of the 2019 study (Figure 1.1A). Interestingly, GC continued to increase in OH after 25 DAS. Overhead sprinklers are used for frost protection on cranberries and other horticultural crops during freezing temperatures (Olszewski et al., 2017). Therefore, it is possible the sprinklers in this study mitigated freezing of the tall fescue leaves and improved growth in OH after 25 DAS, but further research would be necessary to confirm this.

On 11 DAS, 2019, which was the first measurement after the erosion covers were removed, OH was similar to all SDI treatments (Figure 1.2A). However, thereafter GC generally increased faster in the three SDI treatments than in OH. In AGD, GC was lower than in SDI 2x and SDI 3x on 11 DAS and by the last measurement date (32 DAS; 1 Nov.), AGD was lower than all other irrigation treatments (40% GC) including OH.

In 2020, GC was similar among irrigation treatments at 12 DAS, which was the first measurement date after removal of the erosion covers (Figure 1.2B). By 15 DAS, GC was higher in SDI 1x than in AGD and OH. In OH, GC was consistently the lowest numerically among irrigation treatments throughout 2020, although it was never statistically lower than ABD. At 19, 22 and 26 DAS, GC trended higher in SDI 2x and SDI 1x and by the end of the study (26 DAS), GC was highest among treatments in both SDI 2x and SDI 1x. Interestingly, SDI 3x did not perform as well in 2020 as in 2019, and by the end of 2020 (26 DAS), GC in SDI 3x was lower than in SDI 1x and SDI 2x and similar to AGD and OH. Nevertheless, GC was above 70% in all irrigation treatments by 26 DAS 2020.

It is notable that GC generally increased faster in SDI than in either the traditional OH (control) or AGD irrigation treatments. Higher turf quality in SDI than OH was observed in warm-season turfgrasses (Schiavon et al., 2014), but to our knowledge it has not been reported for cool-season turfgrasses. Irrigation with OH more frequently than three times daily may be necessary, or perhaps the fine-textured soils in our study resulted in more even distribution of soil moisture in SDI than OH. Also, in 2020 GC increased faster in SDI 1x and 2x than in SDI 3x. This may be a result of the soil surface remaining wetter longer in SDI 2x and SDI 1x than in any other treatment after irrigations. Visual observations indicated smaller areas of surface wetting above the emitters in SDI 3x than in SDI 1x and SDI 2x, which may have slowed the increase in GC in SDI 3x in 2020. Smaller wetting areas in SDI 3x were likely a result of less water applied at each irrigation event (50% ET_o) compared to SDI 1x and SDI 2x (150% and 75% ET_o, respectively). Better performance of SDI 3x in 2019 may have been a result of more precipitation in 2019 (91.2 mm) than 2020 (29.2 mm) (Figure 1.1), which likely wetted the surface between the driplines more frequently and thus, improved establishment in SDI 3x compared with 2020.

Despite the protective covers, erosion of seeds was observed after rainfall in a few plots of all irrigation treatments during the first week after seeding in 2019. Four rainfall events resulted in 71.4 mm during the first week in 2019 compared to only 13.5 mm in 2020 during the same period when seed covers were installed (Figure 1.1). On average, GC was lower in 2019 than in 2020 (Figure 1.2). For example, the highest GC in 2019 was <68%, whereas in 2020 all irrigation treatments exceeded that value by the end of the study. Lower GC in 2019 may have been caused, in part, by the partial erosion of seedbeds observed during the first week of 2019, as well as because of lower temperatures during the study in 2019 than 2020.

Visual Turfgrass Quality

Turfgrass quality was similar among irrigation treatments in 2019 with the exception of 25 DAS, when TQ was lower in AGD than in SDI 1x and 3x (Figure 1.3A). Numerically, TQ in AGD was lowest among treatments throughout 2019 and by the end of the study, AGD was the only irrigation treatment with TQ below the minimally acceptable level (TQ=6).

In 2020, TQ was generally highest in SDI 1x and 2x and lowest in OH (Figure 1.3B). On the first measurement date after removal of the erosion cover (12 DAS), TQ was highest in SDI 1x and lowest in OH among treatments. By 19 DAS, TQ in SDI 2x had increased and was similar to SDI 1x, while TQ remained lowest in OH among treatments. At the end of the experiment in 2020 (33 DAS; 26 Oct. 2020) TQ was higher in SDI 2x and 1x than in AGD or OH, and all SDI treatments were higher than OH. It is possible that more frequent irrigation (than 3x per day) in OH may have improved establishment in this study; additional research is required to investigate that possibility. Nevertheless, all irrigation treatments were above minimally acceptable TQ at the end of 2020.

On average, TQ was better in 2020 than in 2019. In 2019, acceptable TQ was not observed in any irrigation treatment until the last measurement date (32 DAS) and even then, TQ remained below acceptable in AGD. In 2020, all irrigation treatments except OH surpassed minimally acceptable TQ by 26 DAS, and even OH reached acceptable quality at 33 DAS. By the end of 2020 (33 DAS), TQ was excellent in all SDI treatments (TQ>7).

Ground-Based Measurements of Normalized Difference Vegetation Index

At 11 DAS in 2019, which was the first measurement date after removal of the erosion covers, NDVI was higher in all SDI treatments than in AGD and OH (Figure 1.4A). The NDVI remained highest in all SDI among treatments throughout 2019 with the exception of 18 DAS, when SDI 1x was lower than SDI 2x and similar to AGD and OH. Thereafter, NDVI remained lower in SDI 1x than SDI 2x and was lowest among treatments in OH and AGD. These trends among treatments were similar to GC and to a lesser extent, TQ (Figure 1.2A and 1.3A).

Throughout the 2020 study, NDVI was generally highest among treatments in SDI 1x and SDI 2x (Figure 1.4B). On 12 DAS, which was the first measurement day after removal of the erosion cover, NDVI was highest among treatments in SDI 1x. By the third measurement date (19 DAS), NDVI was highest in both SDI 1x and SDI 2x. Conversely, NDVI trended lower in OH, AGD, and SDI 3x throughout 2020 and by the end of the study (26 and 29 DAS), NDVI was significantly lower in OH, AGD, and SDI 3x than SDI 2x and SDI 1x. As was observed in GC and TQ in 2020 (Figures 1.2B and 1.3B), NDVI in SDI 3x became similar to OH and AGD as the study progressed, indicating poorer establishment of turfgrass in SDI 3x than in SDI 1x and 2x (Figure 1.4B) for reasons that were discussed earlier.

Overall, NDVI averaged higher in 2020 than in 2019, which was similar to patterns in GC and TQ and was likely related to both lower temperatures and erosion of seeds from some plots during 4 intense rainfall events (71.4 mm total) early in the 2019 study. Also, NDVI measurements indicated turfgrass establishment was similar among SDI treatments in 2019 but poorer in SDI 3x than SDI 1x and 2x in 2020. In both years, NDVI was consistently lowest in OH and AGD among treatments.

Drone-Based Measurements of Normalized Difference Vegetation Index

On 8 DAS in 2019, which was early in the study and only two days after erosion covers were removed, sUAS-based NDVI was higher in all SDI treatments than in AGD, and SDI 3x was also higher than OH (Figure 1.5). In 2020, sUAS based NDVI was measured on three dates representing approximately the early (13 DAS), middle (20 DAS), and end (32 DAS) points of the study (Figure 1.6). On 13 DAS, NDVI was highest among treatments in SDI 1x, and AGD was lower than all SDI treatments. Thereafter, on 20 and 32 DAS, NDVI was higher in SDI 1x and 2x than in all other treatments including SDI 3x, which was similar to OH and AGD.

Comparisons between sUAS- and ground-based NDVI were not identical, but that is expected because of the different sensors and techniques used and because measurements with sUAS and handheld devices were taken on different days. Nevertheless, sUAS-based NDVI was similar to ground-based NDVI in both years. For example, in 2019, sUAS- and ground-based NDVI was higher in all SDI than in AGD early in the study (Figures 1.4A and 1.5). In 2020, both sUAS- and ground-based NDVI was highest in SDI 1x among treatments early in the study, and higher in SDI 1x and 2x among treatments at the mid and end points of the study (Figures 1.4B and 1.6). Other researchers have also reported good agreement between sUAS- and ground-based measurements of NDVI (Hong et al, 2019, Zhang et al., 2019).

An aerial image of NDVI from 13 DAS, 2020 illustrates variation of NDVI across the irrigation treatment areas and relationships between color and NDVI values (Figure 1.7). Values of NDVI from sUAS were extracted on each date from pixels within each plot, as described earlier.

Volumetric Water Content

Soil moisture was generally higher in AGD than all SDI treatments in both years and higher in OH than SDI treatments in 2019, which may have been an effect of the application of water directly to the soil surface in AGD and OH (Figure 1.8). However, higher VWC in AGD (both years) and OH (2019) did not correlate to better establishment of turfgrass (Figures 1.2 to 1.6). This may be because VWC was relatively high in all treatments in both years (>28% in 2019 and >26% in 2020), indicating all plots were well-watered. In addition, measurements of VWC at 0-7.6 cm didn't necessarily represent moisture in the thin surface layer where the seeds were located.

Conclusions

Overall, our results demonstrated that tall fescue turfgrass can be established from seed with SDI in fine-textured soils in a transition zone climate. Interestingly, establishment was generally better in all SDI treatments than in AGD or the traditional OH (control), based on measurements of GC, TQ, and NDVI. Furthermore, SDI 2x consistently established tall fescue faster than SDI 3x and, to a lesser degree, than SDI 1x, which demonstrates the importance of proper irrigation frequency in fine-textured soils when establishing turfgrass from seed with SDI.

Cultivation method did not affect GC, TQ, NDVI, or VWC, which indicates that either core aerification and verticutting cultivation techniques could be used to create seedbeds for turfgrass establishment using SDI. Although aeration at 7.62 cm (as in this study) would not be expected to damage an SDI system buried at a 15.24 cm depth, this research confirmed it to be safe. Further research is required to investigate deeper aeration or aeration where dripline placement is shallower (e.g., 10 cm).

Turfgrass protective covers have been shown to improve seed establishment and therefore, the use of frost covers during the first six to seven days immediately after seeding may have affected the results of our study, although that was not evaluated. Research is limited regarding the use of turfgrass protective covers for establishment of seeded turfgrass in conjunction with subsurface drip irrigation (SDI). Therefore, a second study was conducted to investigate the effects of covers on the establishment of turfgrass from seed with SDI, which is presented in chapter two.

Our results generally indicated poorer establishment with AGD than with SDI. Regardless, AGD was similar to OH and may be suitable for portable roadside irrigation during the establishment of seeded turfgrass where no other irrigation is available, as has been recommended by others. More research is needed to evaluate the establishment of turfgrass using AGD, including the effects of different irrigation frequencies and runtimes. Nevertheless, our results indicate that where SDI is available, it is preferable to AGD in the establishment of turfgrass from seed under the conditions of our study.

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Figure 1.1. Precipitation and air temperature for each study period during 2019 (A) and 2020 (B).

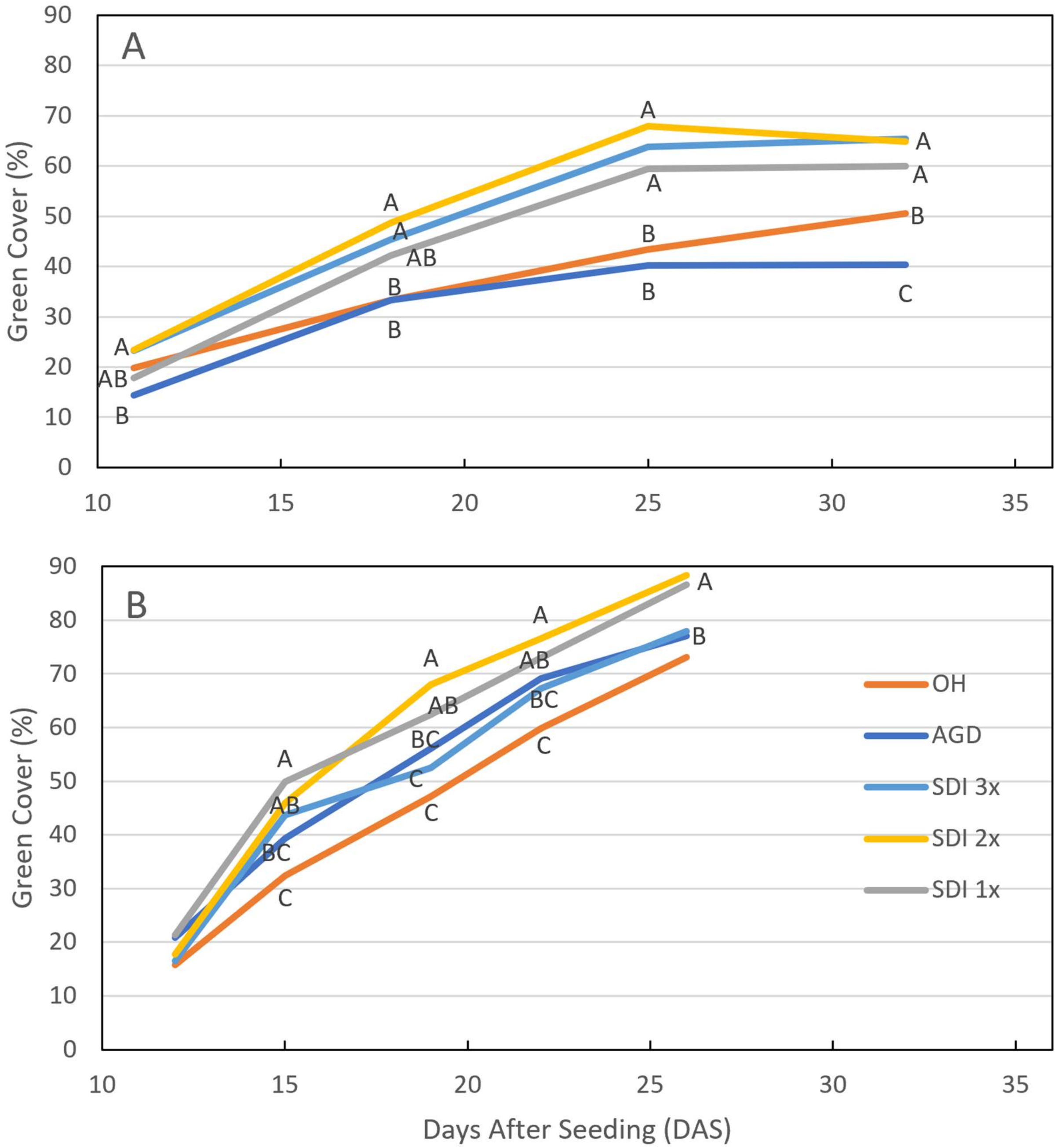

Figure 1.2. Green cover for each irrigation treatment on each measurement date during 2019 (A) and 2020 (B). Irrigation treatments included: overhead sprinkler irrigation (OH), aboveground drip irrigation (AGD), subsurface drip irrigation (SDI) applied three times per day (SDI 3x), SDI applied twice per day (SDI 2x), and SDI applied once per day (SDI 1x). Within each measurement date, means with the same letter are not significantly different at α = 0.05.

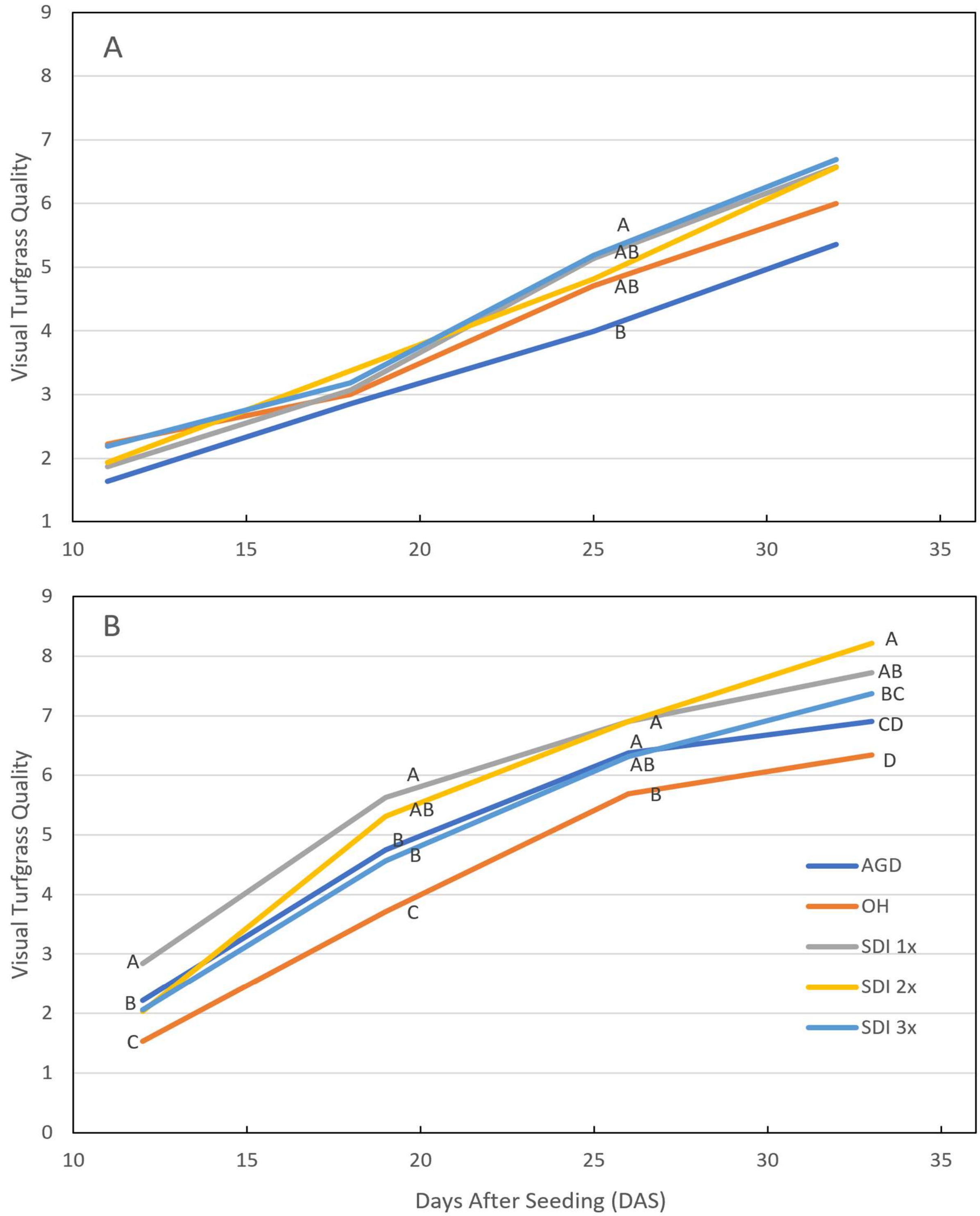

Figure 1.3. Visual turfgrass quality for each irrigation treatment on each measurement date during 2019 (A) and 2020 (B). Irrigation treatments included: overhead irrigation (OH); aboveground drip irrigation (AGD); subsurface drip irrigation (SDI) applied three times per day (SDI 3x); SDI applied twice per day (SDI 2x); and SDI applied once per day (SDI 1x). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

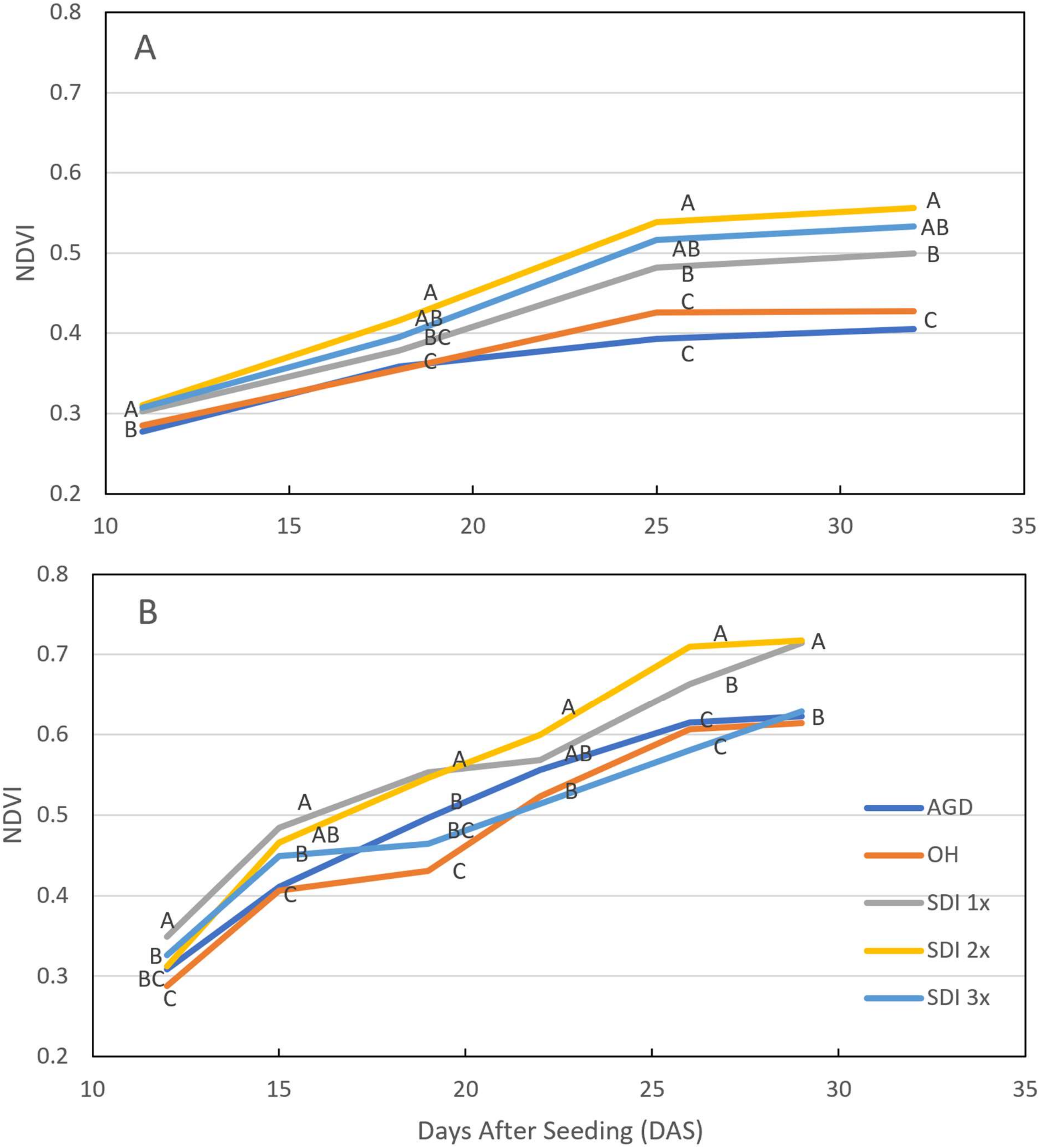

Figure 1.4. Analysis of ground-based normalized difference vegetation index (NDVI) for each irrigation treatment on each measurement date during 2019 (A) and 2020 (B). Irrigation treatments included: overhead irrigation (OH); aboveground drip irrigation (AGD); SDI applied three times per day (SDI 3x); SDI applied twice per day (SDI 2x); and SDI applied once per day (SDI 1x). Within each measurement date, means with the same letter are not significantly different at α = 0.05.

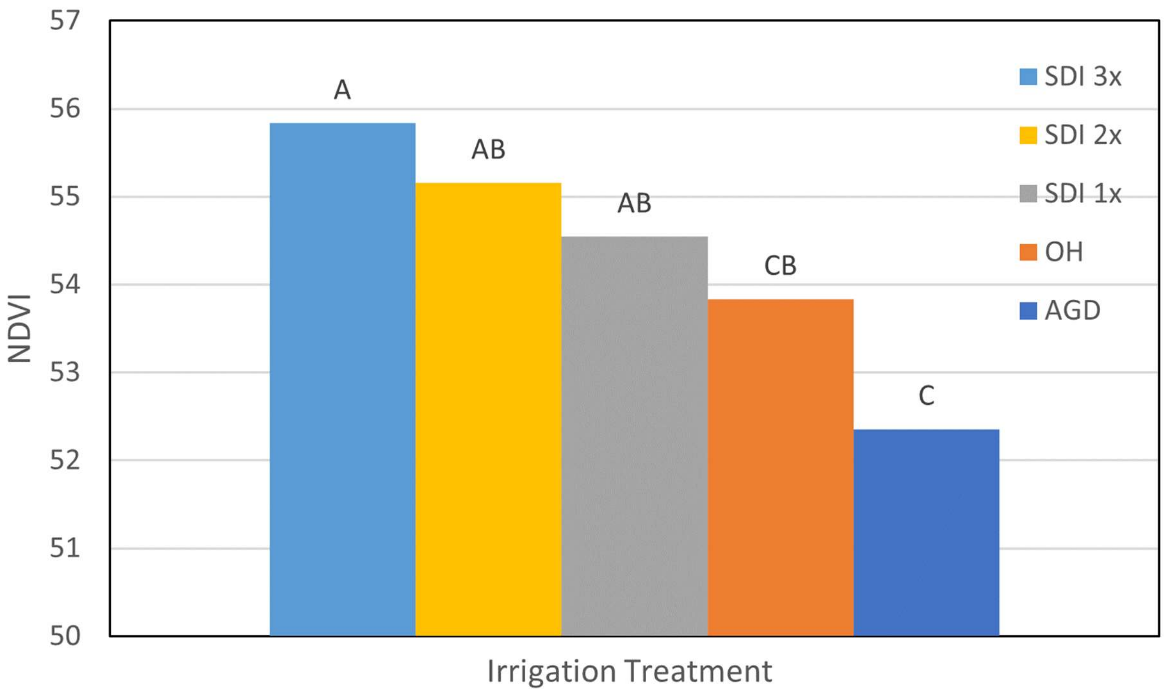

Figure 1.5. Analysis for drone-based normalized difference vegetation index (NDVI) for each irrigation treatment at 8 days after seeding (DAS) during 2019. Irrigation treatments included: overhead irrigation (OH); aboveground drip irrigation (AGD); SDI applied three times per day (SDI 3x); SDI applied twice per day (SDI 2x); and SDI applied once per day (SDI 1x). Means with the same letter are not significantly different at $\alpha = 0.05$.

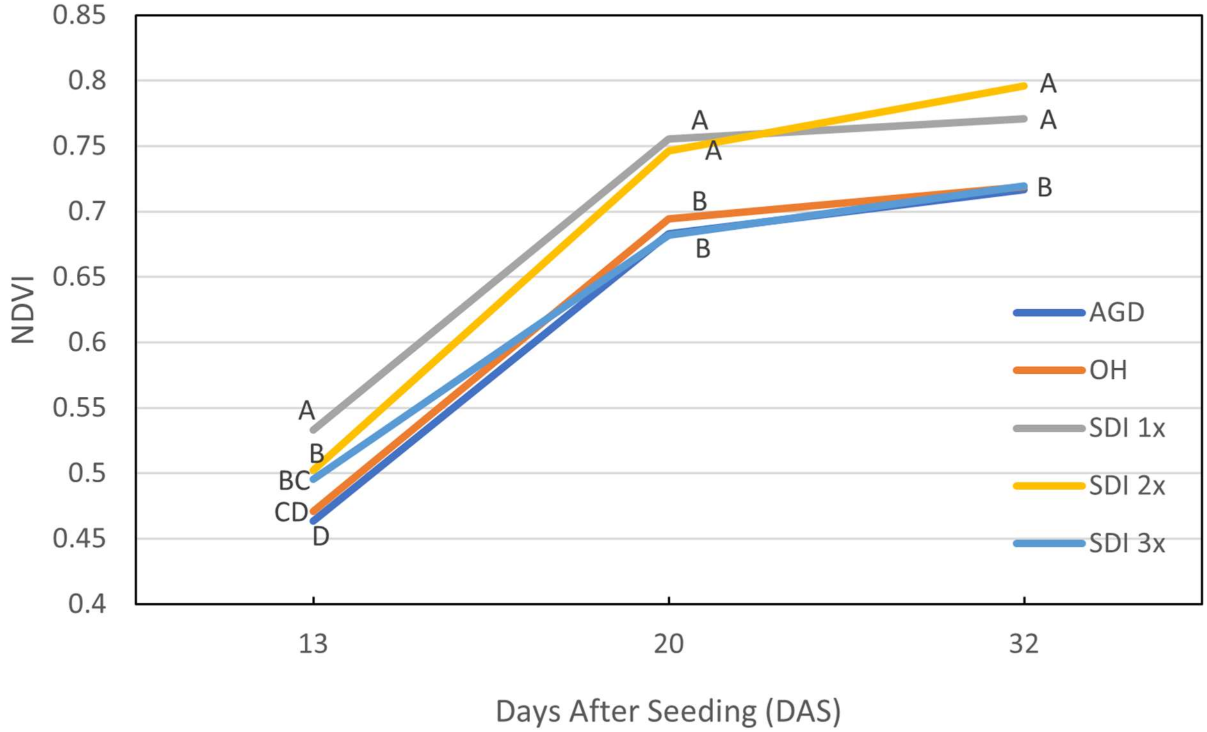

Figure 1.6. Analysis for drone-based normalized difference vegetation index (NDVI) for each irrigation treatment on each measurement date during 2020. Irrigation treatments included: overhead irrigation (OH); aboveground drip irrigation (AGD); SDI applied three times per day (SDI 3x); SDI applied twice per day (SDI 2x); and SDI applied once per day (SDI 1x). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

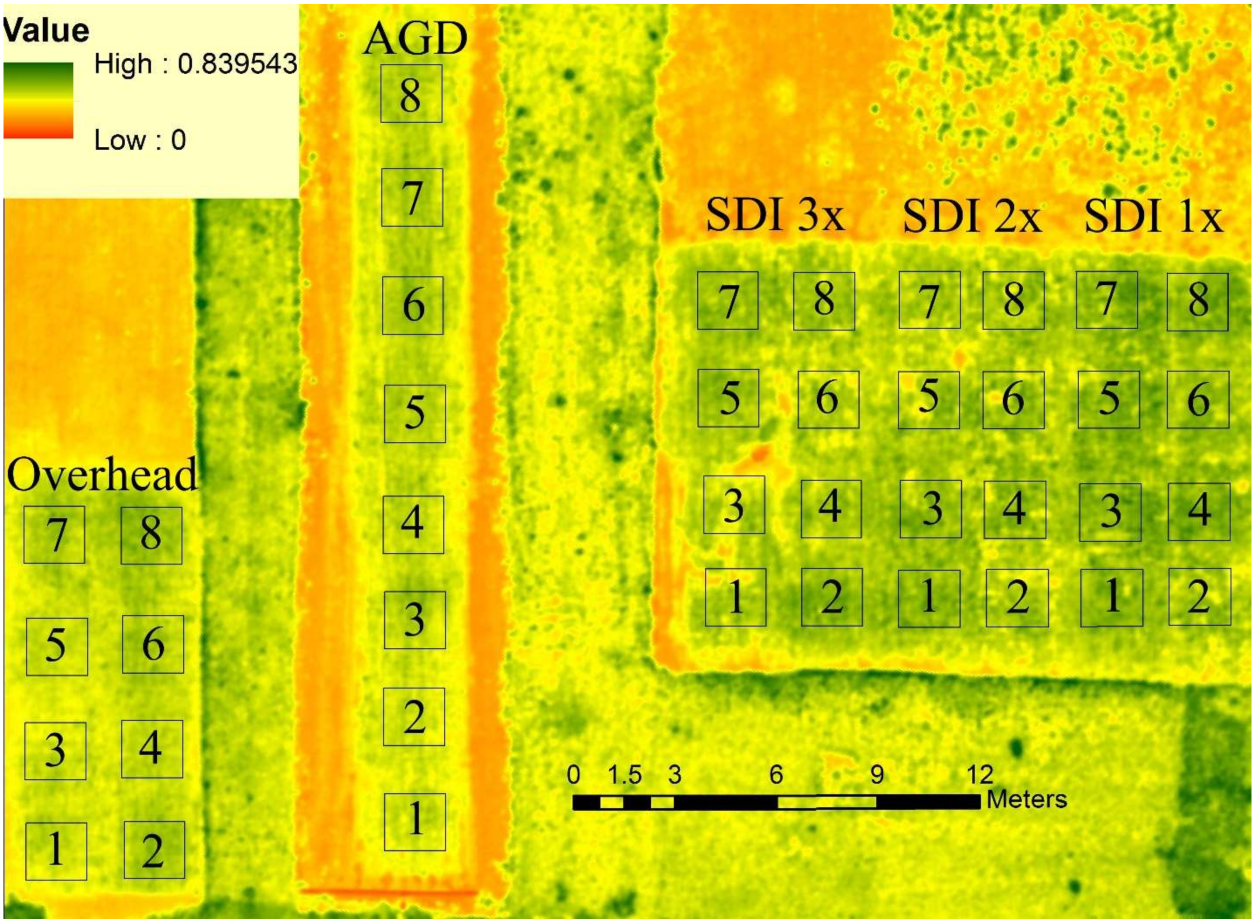

Figure 1.7. Analysis for drone-based normalized difference vegetation index (NDVI) spectral reflectance imaging at 13 days after seeding (DAS) in 2020. Each irrigation treatment on each measurement date during 2020. Irrigation treatments included: overhead irrigation (OH); aboveground drip irrigation (AGD); SDI applied three times per day (SDI 3x); SDI applied twice per day (SDI 2x); and SDI applied once per day (SDI 1x). Numbered squares represent individual plots within irrigation treatments.

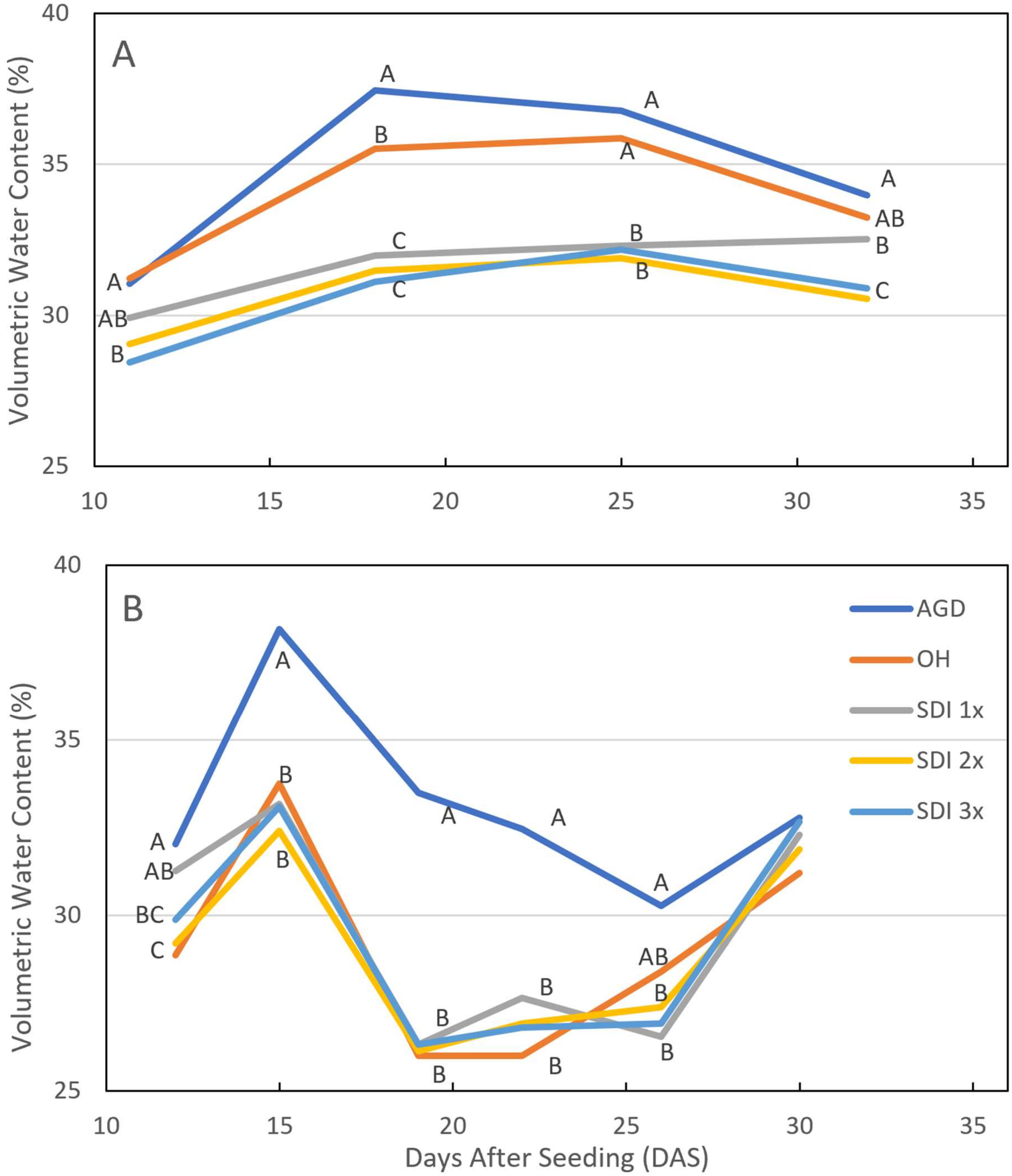

Figure 1.8. Analysis of volumetric water content (VWC) for each irrigation treatment on each measurement date during 2019 (A) and 2020 (B). Irrigation treatments included: overhead irrigation (OH); aboveground drip irrigation (AGD); SDI applied three times per day (SDI 3x); SDI applied twice per day (SDI 2x); and SDI applied once per day (SDI 1x). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

Chapter 2 - Establishing Tall Fescue from Seed with Covers and Drip Irrigation Methods

Abstract

The use of covers may improve establishment of seeded turfgrass but their use for turfgrass establishment in combination with drip irrigation techniques has not been evaluated. In this study, repeated twice in the spring of 2020 near Manhattan, KS, we investigated the effects of two cover types and three irrigation methods on establishment of seeded tall fescue turfgrass [*Festuca arundinacea* (Schreb.)]. Turfgrass cover types included: 1) polyester mesh (PM); 2) straw blanket (SB); and 3) no cover (NC) (control). Irrigation treatments were: 1) subsurface drip irrigation (SDI); 2) aboveground drip irrigation (AGD); and 3) overhead sprinkler irrigation (OH; control)**.** Establishment was evaluated with measurements of green cover (GC), normalized difference vegetation index (NDVI), and visual turfgrass quality (TQ). Establishment was improved with both cover types compared to NC, generally in the order of, from highest to lowest, PM > SB > NC in both trials, but PM and SB became similar over time. Soil-surface temperature averaged higher in PM (14 ºC) than SB (9.5 ºC) and NC (8.6 ºC) during the first 12 d after seeding when covers were installed. Results indicate covers mitigate low temperature extremes and intense rainfall that can erode seedbeds and thus, benefit spring establishment of seeded, cool-season turfgrass in transition zone climates. Differences among irrigation treatments in this study were minimal, but the use of a protective cover is recommended when establishing turfgrass from seed.

Introduction

Covers are frequently used to establish turfgrass. Covers may increase germination and establishment rates of seeded turfgrass by mitigating soil temperature during cold weather, conserving soil moisture, and reducing erosion (Patton et al., 2010). In chapter one, covers were used to protect seedbeds during the first week after seeding in a study that investigated the establishment of turfgrass from seed when using subsurface and surface drip irrigation. It was suspected the covers may have impacted establishment rates, but those effects were not evaluated. To our knowledge, no studies have examined the effects of covers in combination with drip irrigation technologies when establishing turfgrass from seed.

Subsurface drip irrigation (SDI) in turfgrass management has gained attention, in part because of its potential for conserving water (Leinauer and Devitt, 2013). Because SDI applies water directly in the root zone, less water is lost through surface evaporation, wind drift, or run-off than with traditional overhead sprinkler methods (Niazi et al., 2018). When installed, managed, and maintained correctly, SDI has the potential to apply water uniformly and efficiently (Reich et al., 2014). However, before implementing SDI for turfgrass management, a number of factors must be considered, such as, the reliability of using SDI to establish seeded turfgrass, and if covers could improve establishment rates when using SDI.

In general, few studies have investigated the use of SDI for turfgrass irrigation. Of those studies, most have been conducted in sandy loam soils in the arid southwestern United States. For example, turfgrass quality was similar between plots maintained with SDI and traditional overhead sprinkler irrigation in Las Cruces, NM (Leinauer et al., 2010; Leinauer et al., 2018; Serena et al., 2016; Seviostianova et al., 2011a & 2011b; and Suarez-Rey et al. 2000). Even fewer studies have evaluated the establishment of turfgrass using SDI. In Las Cruces, NM, as well as at another site in California with similar sandy soils, cool- and warm-season turfgrass were successfully established from seed or sod using SDI (Schiavon et al., 2013; Schiavon et al., 2015; Serena et al., 2014). Successful establishment in those results indicated good potential for wider use of SDI for turfgrass management beyond the conditions of those studies. However, more research is needed to evaluate the use if SDI in establishing turfgrass in other soil types and climates, and to evaluate the effectiveness of using covers during establishment with SDI.

In the transition zone of the United States, fall establishment is typically recommended for seeded cool season turfgrasses (Fagerness 2002). However, spring establishment is sometimes required, such as where there may be significant winter damage to turf or if the turf manager was not able to seed in the fall. In early spring, soil temperatures may be below optimal for turf establishment, and wide ambient temperature fluctuations may cause additional stress on emerging seedlings (Samples and Sorochan, 2007). Intense spring rains may also erode and damage seedbeds and emerging seedlings. Therefore, protective covers may improve cool-season turfgrass establishment rates by mitigating low temperature extremes, reducing drying rates of the soil surface, and reducing the potential for erosion of seedbeds or seedlings during intense rainfall (Beard, 1966; Dudeck et al., 1970; Samples and Sorochan, 2007; Patton et al., 2010).

Protective turfgrass seed covers may consist of natural (e.g., loose straw) or synthetic materials, and each has positive and negative attributes. For example, loose straw is cost-effective but if applied too thick it can restrict seed germination by shading or suffocation and could increase the potential for disease on new seedlings (Landschoot, 2016). Conversely, if applied too thin it is little better than no cover (e.g., does not prevent erosion of seeds or seedlings, reduce soil drying rates, or moderate low temperature extremes). Synthetic covers, such as vented or unvented polyethylene material, provide more uniform coverage but are more expensive and somewhat labor intensive to install and remove. Biodegradable covers include hydromulching, pelletized mulches from compressed newspaper, and plant fiber mulches; the latter is one of the least effective but also the lowest cost covers available for turf (Landschoot, 2016).

In Mississippi, 12 different turf covers were evaluated for their ability to protect bermudagrass greens during winter when temperatures were predicted to drop to or below -4°C (Goatley et al., 2007). Results indicated the covers warmed the surface of the greens during the day but minimum temperatures at night were not different from the uncovered control. Those authors concluded that all cover types provided some degree of potentially desirable temperature modification, but selection and use would depend on the needs of the turf manager. Lee (2013) also found that using polyvinyl chloride covers, with or without holes for ventilation, aided in the winter survival of Kentucky bluegrass in Asan, Korea.

In a spring study in Iowa, recovery of Kentucky bluegrass (*Poa pratensis* L.) from fraze mowing was evaluated when seeded at two rates and an unseeded control, and when covered with translucent, woven polyethylene covers or uncovered (control) (Hansen and Christians, 2015). All covered plots initially recovered faster than uncovered plots, but differences converged within 2 to 5 weeks after the covers were removed.

Patton *et al.*, (2010) investigated the effects of ten different protective turf covers on the establishment of five warm-season turfgrasses during summer. Overall, the best performing covers consisted of a polymer-based mesh. Conversely, loose straw was rated poorly, possibly because it may have moved during intense rainfall and thus, damaged seedlings or allowed erosion of the seedbed. In that study, seedlings emerged first under polyethylene covers, but excessively high soil temperatures (between 43.7 — 46.0°C) under those covers also injured the seedlings and reduced the percentage of established turfgrass, whereas soil temperatures in the uncovered control only reached 33.4 — 34.7°C.

The contrasting results among the aforementioned studies illustrate the different effects of covers when used during the high and low temperatures of summer and winter, respectively. At this time, however, no research has evaluated the effects of protective covers on the establishment of turfgrass from seed in any season when using SDI. In our study, we investigated the capability of using protective covers to moderate soil temperatures and, hopefully, to improve the establishment of cool-season turfgrass when using SDI during the spring, in fine textured soils in the U.S. transition zone. Our specific objectives were to investigate the establishment of tall fescue turfgrass from seed using a) two types of turf protective covers and an uncovered control; in conjunction with b) SDI, aboveground drip irrigation (AGD), and overhead sprinkler irrigation (OH; control). Tall fescue was selected because it is the most widely used turfgrass in residential lawns in some areas of the transition zone (Bremer et al., 2012) and it is popular on US golf courses (Gelernter et al., 2017).

Materials and Methods

Maintenance

Research was conducted in the spring of 2020 at the Rocky Ford Turfgrass Research Center, Manhattan, Kan. (39º13’53’’N, 96º34’51’’W). The soil at the site was a Chase silty clay loam soil (fine, smectitic, mesic Aquertic Argiudoll). The first trial was seeded when soil temperature at 5 cm reached 10°C (24-hr average), which was on 9 Apr. 2020, as determined by a nearby weather station (Figure 2.1) (http://mesonet.k-state.edu/). The second trial was seeded on 2 May 2020, for reference, 5 cm soil temperature depth was 18°C (24-hr average) (http://mesonet.k-state.edu/). The average last frost date in Manhattan, KS, is 15 April, but the last frost in 2020 was 20 May.

On 19 Mar. 2020, which was three weeks before plots were seeded in the first trial, glyphosate (Glyphomate 41, PBI/ Gordon Corporation)((N-(phosphonomethyl)glycine) in the form of isopropylamine salt) was applied at a rate of 18.31 kg a.i. ha^{-1} to existing tall fescue. After turning brown, all dead biomass was removed from the surface with a sod cutter (Jr. Sod Cutter, Ryan). A triplex mower with verticutting reels (04416 Toro Verticut reels, The Toro Company), set to cut rows at a depth of 1.27 cm and spaced 1.27 cm apart, was used to create a seedbed. Tall fescue turfgrass seed was then spread using a shaker bottle in multiple directions at a rate of 390.54 kg ha^{-1} and lightly raked to ensure good seed-to-soil contact. The tall fescue seed blend included the cultivars ‘Copious’ (38.67%), ‘Reunion’ (38.56%), and ‘Starfire II’ (22.27%) (Lesco Inc., All Pro Transition Blend). Urea fertilizer (Humic Coated Urea, The Andersons) was applied at a rate of 110.83 kg ha^{-1} on 1 May in trial 1and 23 May in trial 2.

The experiment was arranged in a split-plot randomized complete block design with three irrigation treatments applied to whole plots and three cover treatments applied to split-plots within each whole plot. The three irrigation treatments were each represented by a single irrigation zone (37 m by 6.10 m), with each zone divided into three whole plots (5.49 m by 9.14 m); all irrigation zones in the study were adjacent to each other. Irrigation treatments included: 1) overhead sprinkler irrigation (OH); 2) aboveground pressure-compensating dripline irrigation (AGD); and 3) SDI irrigation. Within each whole plot, the three cover treatments were randomly applied to split plots (1.83 m by 3.05 m), for a total of 27 subplots in the study. Therefore, each cover treatment was replicated three times per irrigation method. Cover treatments included: 1) polyester mesh (PM) (0.5 oz. Deluxe Seed and Plant Guard Frost Blanket, DeWitt); (2) straw blanket (SB) (Single Net Blanket, SiteOne Landscape Supply); and 3) no cover (NC), serving as the control. Covers were installed immediately after seeding and landscape staples (Gardener's Supply Company) were used to secure the covers to each subplot. Covers were removed on 13 and 12 days after seeding (DAS) in trials 1 and 2, respectively. Covers were removed when seedling shoots began to appear through the PM covers to avoid damage to seedlings when covers were removed.

Each irrigation zone applied 150% of the reference evapotranspiration estimated from the previous day using data from the onsite weather station. In each irrigation treatment, water was applied three times per day, morning, midday, and late afternoon (approximately 0800, 1300, 1700 CST). Overhead irrigation consisted of ten Hunter I-20 (Hunter Industries) gear-drive rotors with a distribution uniformity of approximately 75%, as determined with an irrigation system audit using catch devices before the first trial. Water was applied in AGD and SDI through driplines at a rate of 20.82 mL min^{-1} (Techline Dripline, Netafim). Driplines were spaced 45.72 cm apart in rows with emitter spacing of 30.5 cm. The only difference between the AGD and SDI was that AGD rested on the soil surface while the SDI was buried in the soil at 15.24 cm.

Measurements

After covers were removed, data were collected twice weekly during both trials, before the second (midday) irrigation application. Percent green cover was measured using a light box and digital camera (Nikon D5000, Nikon Inc.). Images were analyzed using SigmaScan Pro 5 (Systat Software, Inc.) (Karcher and Richardson, 2005), with hue and saturation ratios set at 45/100 and 0/100, respectively. Visual turf quality (TQ) was rated on a 1 to 9 scale (1 = poorest quality, 6 = minimally acceptable, and 9 = highest quality) according to color, texture, density, and uniformity (Morris and Shearman, 1999). Volumetric water content was measured at two locations per split plot using a FieldScout TDR 300 Soil Moisture Meter (Spectrum Technologies).

To evaluate the effects of covers on soil-surface temperatures, soil encapsulated thermocouples were used according to the technique of Ham and Senock (1992). Seedbed surface temperatures were measured every five minutes and averaged and recorded every 60 minutes using a CR1000 datalogger (Campbell Scientific, Inc.). Day and nighttime seedbed temperatures were averaged from all readings taken from 1000 to 1800 (daytime) and 2200 to 0600 CST (nighttime) during the study. Soil-surface temperatures were measured only in SDI because of limitations in sensor and data acquisition availability. One soil encapsulated thermocouple was placed in each split plot.

Normalized difference vegetation index (NDVI) was measured with a hand-held RapidScan CS-45 (Holland Scientific Inc.), although that instrument was under repair and unavailable during the first three weeks of trial 1. Aerial measurements of NDVI were collected with a small unmanned aircraft system within 2.5 hours of local solar noon on 29 May and 12 June 2020. Images were collected with a Micasense RedEdge MX (AgEagle Sensor Systems Inc.) mounted on a fixed-wing drone (eBee X, senseFLY) flown at 75 m, which resulted in a resolution of 5 cm px^{-1}. The resulting JPEG images were then processed into orthomosaics using Agisoft Metashape Professional (v. 1.6.34 build 10732, Agisoft LLC), and treatment effects were analyzed from the orthomosaics in ArcGIS (v. 10.8, ESRI Inc.) by extracting data from a square area that included the center 60% of each plot surface and using the zonal statistics as table feature. Additional details of data analysis of drone images are presented in chapter 1.

Statistical Analysis

Data were analyzed using SAS On Demand for Academics Version 3.8 (SAS Institute Inc., Cary, N.C.). A generalized linear mixed model (GLIMMIX) was used to analyze data using a significance level of P=0.05.

Results and Discussion

There were no irrigation by cover interactions, so data are presented separately for irrigation and covers as main effects. Interactions were present for irrigation by trial and cover by trial, so data are presented separately by trial 1 and trial 2. Soil-surface temperatures, which were only measured in SDI plots, were combined between trials because there was no cover by trial interaction for temperature.

Effects of Covers

The order of GC from highest to lowest was generally PM > SB > NC throughout both trials (Figured 2.1A and 2.1B). On 14 and 12 DAS in trials 1 and 2, respectively, which was the first measurement day after covers were removed in each trial, GC was higher in PM than either SB or NC plots and remained highest among treatments until late in the study when it became similar to SB. Specifically, GC in PM became similar to SB on 38 DAS in trial 1, although GC then rebounded in PM and became higher than SB by the end of the study (42 DAS). In trial 2, GC became similar between PM and SB by the last two measurement days of the study (36 and 44 DAS). Green cover was always higher in both PM and SB than NC except for the first measurement day in trial 1 (14 DAS), when GC was similar between SB and NC. Numerically, GC was always highest in PM and lowest in NC plots.

Results indicated that installation of PM and SB covers on tall fescue for 12-13 days after spring seeding improved GC for at least one month after covers were removed (the length of each trial in this experiment). Improved germination and coverage of turfgrasses has been observed by others after covers were installed for two weeks after seeding (Portz et al., 1993; Patton et al., 2010). While GC was initially highest among treatments in PM plots, the differences in GC between PM and SB generally abated with time. However, the installation of either type of cover resulted in higher GC compared with NC plots throughout the first month after removal of covers, indicating that either PM or SB covers are preferable to NC, although PM may hold an advantage over SB.

Measurements of NDVI with the handheld device revealed the same order as GC, namely NDVI in PM > SB > NC (Figure 2.2A and 2.2B). This illustrates the close relationship between GC and NDVI, which has been reported by others (Bell et al., 2002; Bremer et al., 2011). In both trials, NDVI was initially higher in PM than in SB and NC treatments after removal of the covers, but differences diminished with time between PM and SB. On the last measurement day in trial 1 (60 DAS), NDVI was statistically higher in PM than SB, but only by 0.02, which may not have had much agronomic significance. In trial 2, NDVI was similar between PM and SB at the end of the study. Throughout both trials, NDVI was lower in NC than in either PM or SB covers.

Drone-based NDVI was measured only twice, on 29 May and 12 June, which corresponded to 50 and 64 DAS in trial 1 and 27 and 41 DAS in trial 2 (Figure 2.3A and 2.3B). In trial 1, NDVI was similar between PM and SB treatments on both dates, while in trial 2, NDVI was higher in PM than SB on 27 DAS, but differences diminished and were similar between PM and SB by 41 DAS. As with GC and ground-based NDVI, this indicated a converging in the differences between PM and SB treatments with time; presumably, because trial 1 (50 and 64 DAS) was three weeks further into the study than trial 2 (27 and 41 DAS), NDVI in trial 1 had already converged between PM and SB. In both trials, NDVI was consistently lower in NC than in PM and SB treatments.

Comparisons between sUAS- and ground-based NDVI were not identical, which is expected because of the different sensors and techniques used, and because measurements with sUAS and handheld devices were taken on different days. Nevertheless, sUAS-based NDVI was similar to ground-based NDVI in both trials. For example, in trial 2 both ground and drone-based NDVI showed the convergence with time of the PM and SB treatments (Figure 2.2B, 2.3B), and both revealed that NC was consistently lower than PM and SB throughout both trials. This supports results from others who have reported good agreement between sUAS- and ground-based measurements of NDVI (Hong et al, 2019; Zhang et al., 2019).

Turfgrass quality was dramatically higher in PM and SB than NC treatments throughout both studies (Figure 2.4). However, TQ was always similar between the PM and SB treatments except for the first measurement day after covers were removed in trial 1 (18 DAS), when TQ was higher in PM than SB. In trial 1, TQ surpassed the minimally acceptable level (TQ=6) by 23 DAS in PM and 27 DAS in SB. In trial 2, TQ surpassed the minimally acceptable level at 19 DAS in both PM and SB covers. By the end of both trials, TQ reached or exceeded a value of 7, which indicates high TQ in both PM and SB treatments.

In both trails, TQ in NC plots never reached the minimally acceptable level (TQ=6), and the highest TQ in either trial was only 2.75 (30 DAS, trial 1) (Figure 2.4). Low TQ in NC was a result of 18.0 mm and 39.6 mm of rainfall in trial 1 and trial 2, respectively, during the first two weeks when covers were installed on PM and SB, which eroded the seedbeds in uncovered (NC) but not in covered plots (PM and SB). This limited the establishment potential for NC plots, but also illustrated the value of protective turf covers.

Daytime soil-surface temperature (10:00-18:00 CST) was higher in the PM than the SB treatment during the period when covers were installed on the plots (0 to 12 days) (Figure 2.5A). However, after the covers were removed the differences in soil-surface temperatures diminished and became similar among treatments (13-20 DAS). Daytime temperature was always similar between the NC and both cover treatments.

Nighttime soil-surface temperature (22:00-6:00 CST) was higher in the PM than the NC treatment as long as covers were installed (0-12 DAS), and was also higher than the SB treatment from 7 to 12 DAS (Figure 2.5B). However, as with daytime temperatures the differences in nighttime soil-surface temperatures diminished and became similar among treatments after the covers were removed (13-20 DAS).

Regardless of the time of day, mean soil-surface temperature was generally highest in PM covered plots (Figure 2.5). This was likely because the PM transmitted 85% of solar radiation to the soil, which warmed the soil surface and then trapped heat under the cover during the day and night. In the SB treatment, the SB likely shaded the soil surface and kept it cooler than in the PM treatment during the day. In the NC treatment, mean daytime soil-surface temperature was numerically higher than in SB, which was likely a result of direct solar radiation warming the soil surface compared with the more shaded SB treatment. At night, however, mean soil-surface temperature was numerically lowest in NC, probably because the absence of covers allowed heat to radiate more rapidly into the atmosphere, resulting in a larger temperature drop compared with covered treatments, where radiative heat loss from the soil surface was reduced by covers.

Consistently higher soil temperature in PM treatment may explain why turfgrass establishment was initially faster than in the SB and NC treatments in this spring study when soil temperatures were low. Light is also an important factor in the germination and establishment of turfgrass (Yeam et al., 1981; Zuk et al., 2005; Shin et al., 2006), and transmission of light along with higher soil temperatures in the PM treatment may also have improved establishment. The strong effects of covers on soil-surface temperatures in this study were undoubtedly a result of changes in the energy balance of the surface (Bremer & Ham, 1999).

Effects of Irrigation

In general, the effects of irrigation were not as pronounced as the effects of covers and were inconsistent between trials. Perhaps the most noticeable irrigation effect was in trial 1, in which GC increased more rapidly and became higher in AGD than SDI and OH by 23 DAS and remained higher through the end of trial 1 (42 DAS; 21 May 2020) (Figure 2.6A). However, higher GC in AGD was not observed in trial 2 but rather, GC was similar among all treatments throughout much of that trial, with the exception of the first and last measurement days (Figure 2.6B). In trial 1, three plots along one side of the AGD zone (one plot each of PM, SB, and NC) were more green than all other plots in AGD, which skewed GC higher in AGD than SDI and OH. The reason for this phenomenon is uncertain but it is possible that this was a low area in the AGD irrigation zone, keeping the surface wetter for longer periods of time. Also, the 26.67 mm rainfall that occurred on 4 May 2020 may have washed the fertilizer application (1 May 2020) to the low side of the AGD zone.

In OH, GC was initially lower than AGD and in both trials and also lower than SDI in trial 2, on the first measurement day after covers were removed (14 and 12 DAS in trials 1 and 2, respectively) (Figure 2.6). But GC was similar between OH and SDI throughout trial 1 and, after the first measurement day in trial 2, GC was similar among all treatments until the last day (44 DAS), when OH was greater than AGD and SDI.

The rate of increase in GC noticeably slowed and even declined after 25 DAS in trial 2, especially in the drip irrigation treatments (SDI and AGD) (Figure 2.6B). This decline in GC was a result of yellowing of the leaf tips that was observed after application of urea fertilizer on 21 DAS (23 May). Although all plots were irrigated immediately after urea was applied, some urea granules did not dissolve completely in the SDI and AGD treatments. When urea is not immediately incorporated, volatilization in the form of ammonia can cause leaf burn (Bowman et al., 1987; Bremner, 1995), and this probably explains the decline in GC in SDI and AGD late in trial 2. In trial 1, urea also had been applied on 21 DAS (1 May), but no obvious effect on GC was observed after fertilization (Figure 2.6A). It is possible that leaf burn in trial 2 was exacerbated by correspondingly higher air and soil temperatures than in trial 1 (Figure 2.1), which can increase volatilization of urea (Bowman et al., 1987). In the first week after urea fertilization, air and soil-surface temperature averaged approximately 7°C and 5.2°C higher, respectively, in trial 2 than in trial 1, primarily because trial 2 was later in the spring than trial 1. While some leaf burn after urea fertilization was observed in OH in trial 2, it was much less than SDI and AGD, probably because the overhead sprinklers in OH improved incorporation of urea granules and thus, minimized urea volatilization and leaf burn. This indicates a potential limitation of SDI and AGD that requires further investigation.

In trial 1, ground-based NDVI was higher in AGD than OH on all measurement dates (12, 54, and 61 DAS) and higher in AGD than SDI on 12 DAS, which was the first measurement day after covers were removed (Figure 2.7). The NDVI was not measured between 12 and 54 DAS because the instrument was being repaired. However, ground-based measurements on 54 and 61 DAS were within three to four days of drone-based NDVI measurements that also indicated higher NDVI in AGD than in OH on both 50 and 64 DAS, and higher NDVI in AGD than SDI on 50 DAS (Figure 2.8). In trial 2, no differences were observed in either ground or drone-based NDVI among irrigation treatments (data not shown), although both indicated increasing NDVI with time. Specifically, ground-based NDVI increased from 0.315 to 0.453 from 19 to 47 DAS and drone-based NDVI from 0.475 to 0.574 from 27 to 41 DAS in trial 2. Higher NDVI in AGD in trial 1 but not in trial 2 was similar to the patterns of GC discussed above. More research is needed to investigate the effects of AGD on turfgrass establishment.

No differences in TQ were observed among treatments in either trial except for the last measurement day in trial 1 (30 DAS; 9 May 2020), when TQ in ABG (6.6) was higher than SDI (4.4), and OH (5.2) was similar to both AGD and SDI. By the end of trial 2, TQ averaged 5.3 among irrigation treatments. The only treatment that reached minimally acceptable TQ (TQ=6) in either trial was AGD at the end of trial 1 (30 DAS) (data not shown). In trial 1, three plots along one side of the AGD zone (one plot each of PM, SB, and NC) were more green than all other plots in AGD, which skewed TQ higher in AGD than SDI and OH, similar to GC results.

Volumetric Water Content

Volumetric water content was always higher than 32% in all treatments, and few significant differences were observed among treatments throughout both trials (data not shown). In trial 1, the only difference observed among treatments was on 23 DAS, when volumetric water content was greater in AGD than OH, but AGD and SDI were similar. In trial 2, volumetric water content in SDI was greater than OH on 25 and 31 DAS and also greater than AGD on 25 DAS. However, there were no clear effects of volumetric water content on turfgrass establishment, probably because it was consistently high in all treatments.

Conclusions

In summary, GC, NDVI, and TQ were higher when plots were covered with PM for the first two weeks after seeding, indicating better establishment of tall fescue from seed in PM than the NC. The PM kept soil surfaces warmer than in uncovered plots over the entire period covers were installed (i.e., soil surface averaged 14°C in PM 9.5°C and 8.6°C in NC, and air temperature averaged 8.5°C; 24-h averages). The SB also improved establishment compared with NC, possibly by preventing erosion of the seedbed, as indicated by higher GC, NDVI, and TQ in SB than in NC. With 18.0 mm of precipitation while covers were on in trial 1 and 39.6 mm of precipitation while covers were on in trial 2, erosion of the seed occurred on NC plots.

The three irrigation methods used in conjunction with protective turfgrass covers did not reveal a difference in either trial. This study concludes that SDI or AGD can establish tall fescue from seed to the same quality as that of OH.

Future research regarding drip irrigation (SDI and AGD) and protective turfgrass covers should investigate the irrigation regime (e.g., watering amounts and frequencies) required to fully incorporate urea fertilizer granules and thus, avoid leaf burn from ammonia volatilization compared to OH, or possibly evaluate the use of injecting nitrogen fertilizer into SDI systems. It is possible that fertilizer granules applied at seeding could be dissolved by covers absorbing water and releasing the water over the entire covered area, this could also be another method to fertilize the whole desired SDI area. More research can be conducted on the comparison of turfgrass covers and how long they take to germinate new seedlings, or how much seed they let wash during weather events that cause soil erosion.

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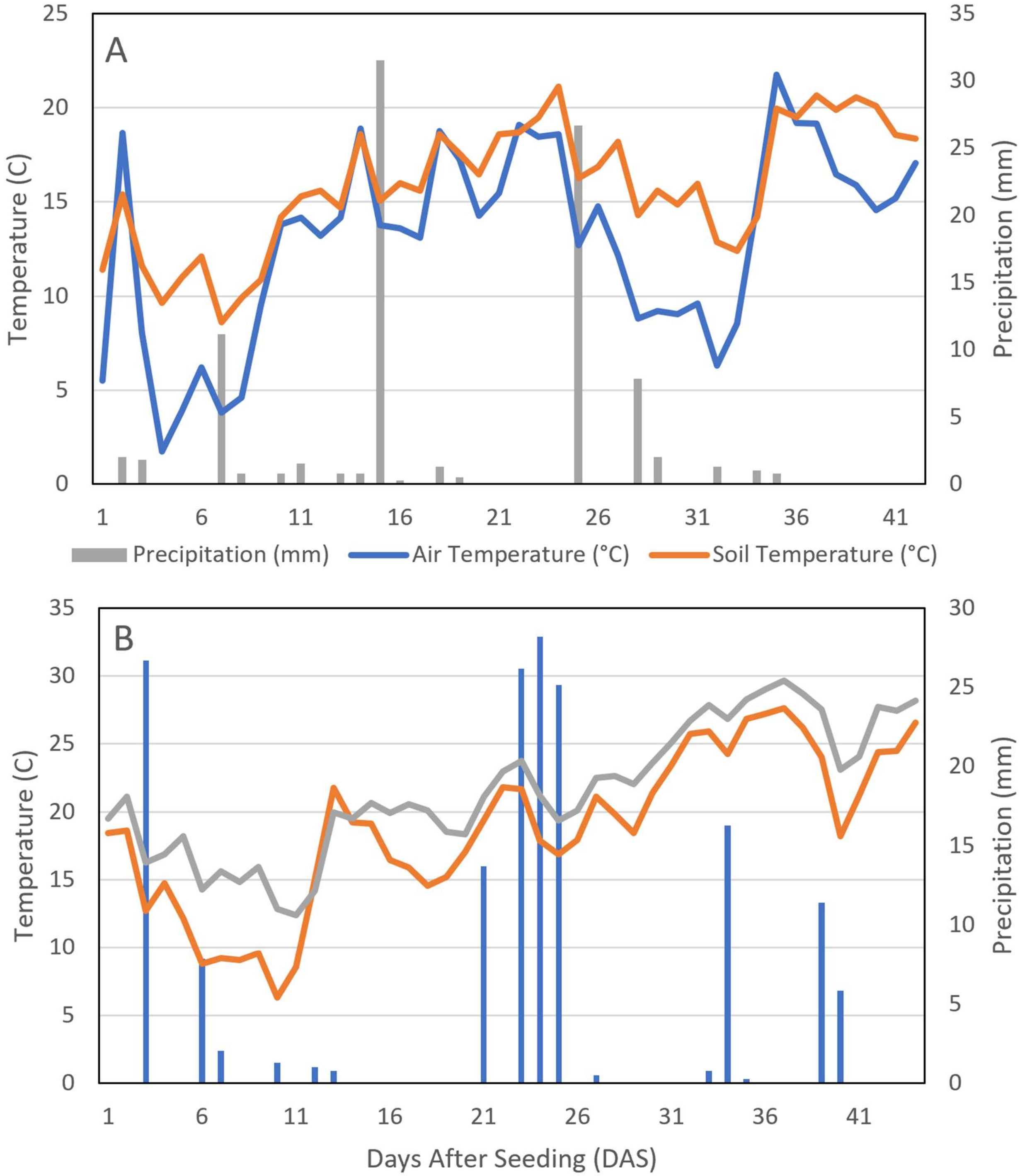

Figure 2.1. Precipitation and air temperature for each study period during trial 1 (A) and trial 2 (B).

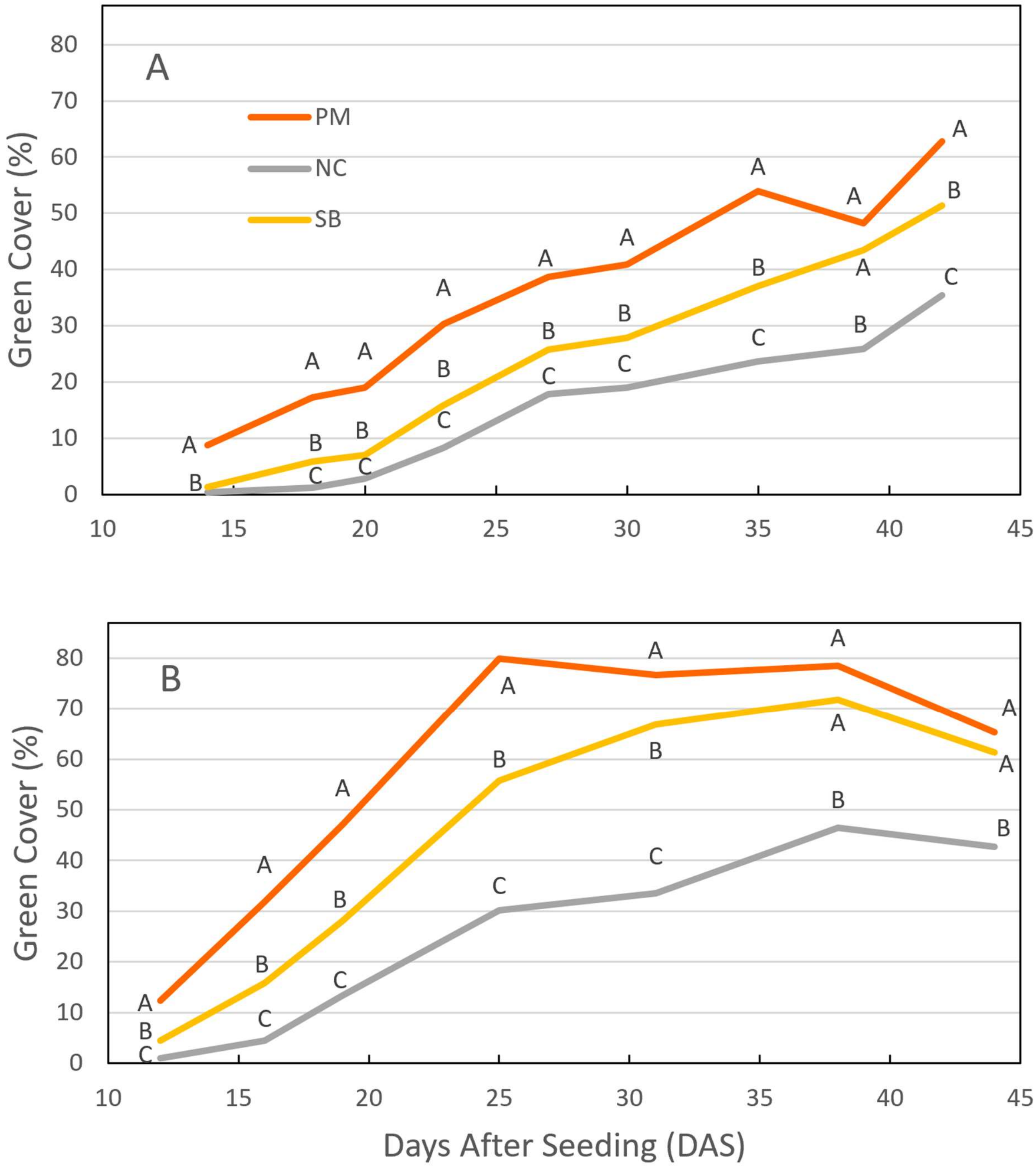

Figure 2.2. Green cover for each cover treatment on each measurement date during Trial 1(A) and Trial 2 (B). Cover treatments included polyester mesh (PM), straw blanket (SB), and no cover (NC). Within each measurement date, means with the same letter are not significantly different at α = 0.05.

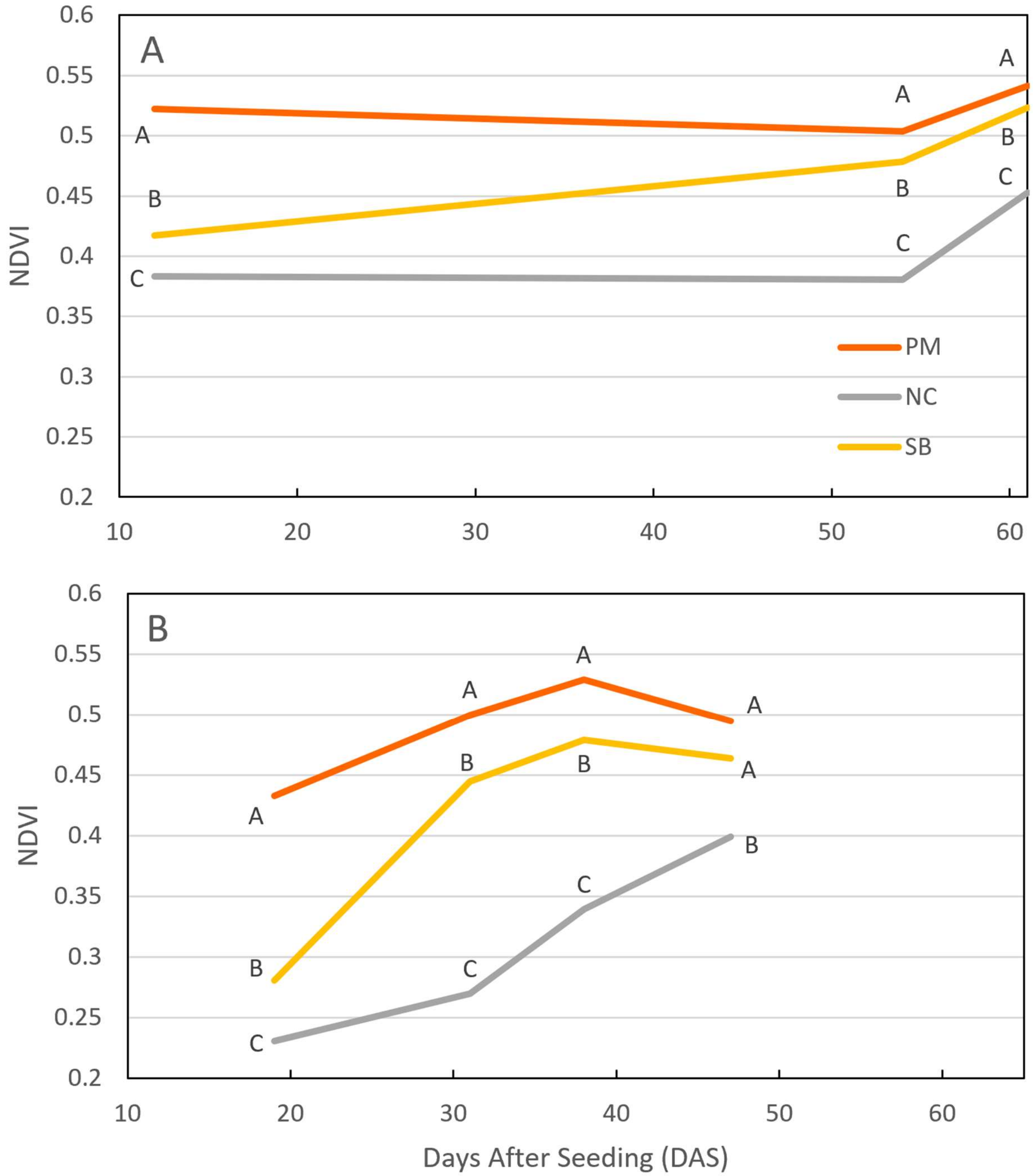

Figure 2.3. Ground-based normalized difference vegetation index (NDVI) for each treatment on each measurement date during Trial 1(A) and Trial 2 (B). Cover treatments included PM (Polyester), SB (Straw), and NC (No Cover). Within each measurement date, means with the same letter are not significantly different at α = 0.05.

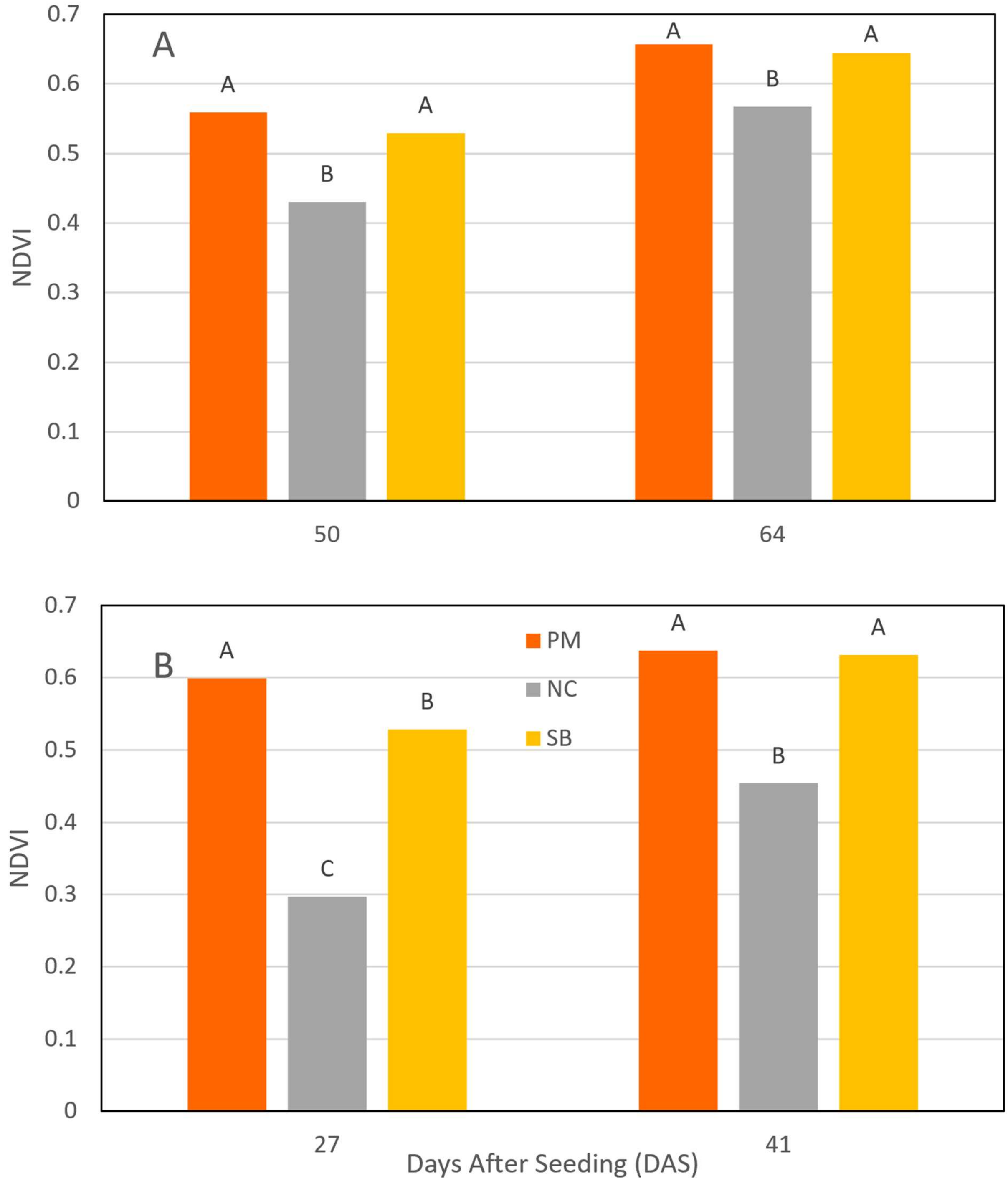

Figure 2.4. Drone-based normalized difference vegetation index (NDVI) for each treatment on each measurement date during Trial 1(A) and Trial 2 (B). Cover treatments included PM (Polyester), SB (Straw), and NC (No Cover). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

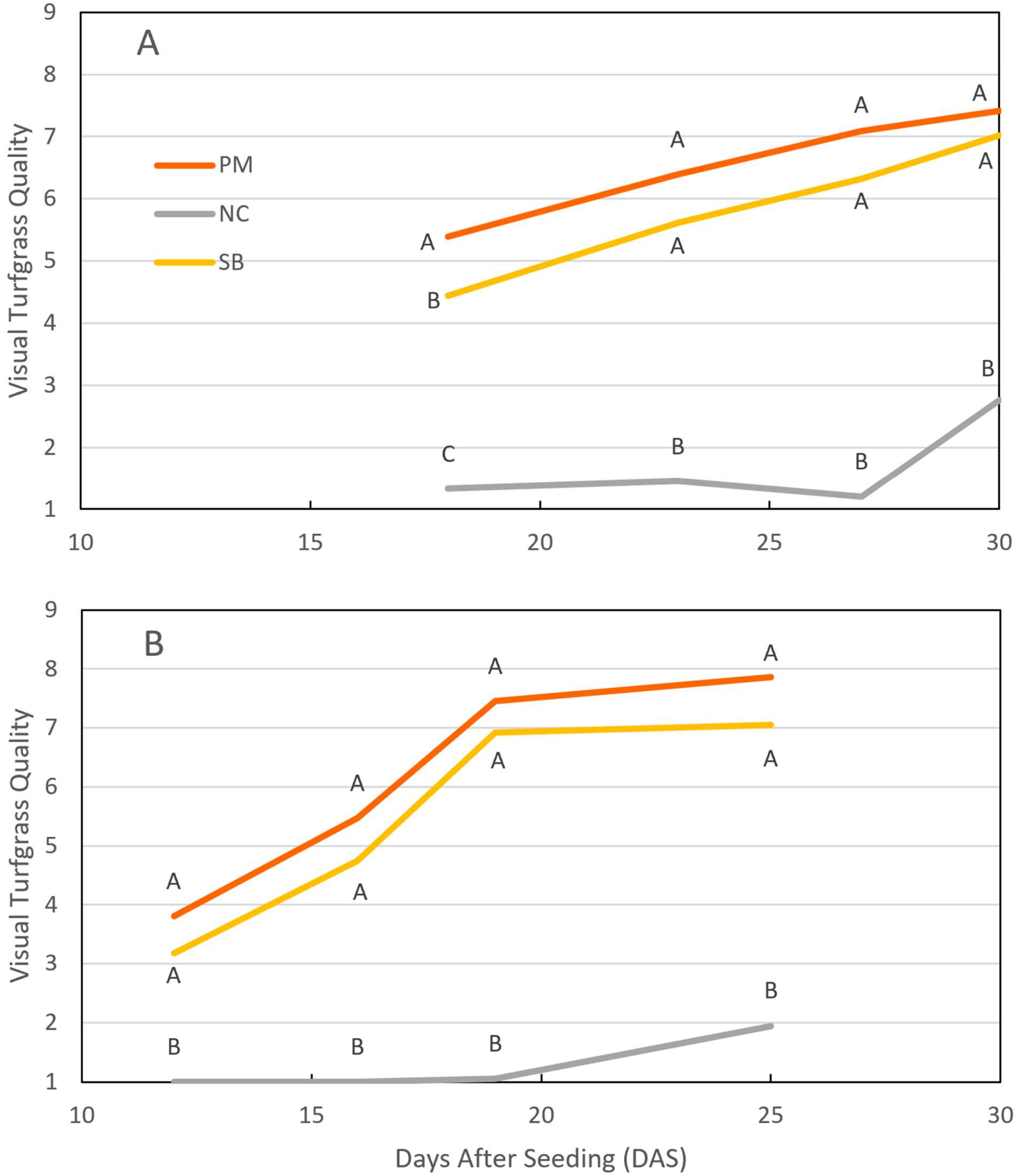

Figure 2.5. Visual turfgrass quality for each treatment on each measurement date during Trial 1(A) and Trial 2 (B). Cover treatments included PM (Polyester), SB (Straw), and NC (No Cover). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

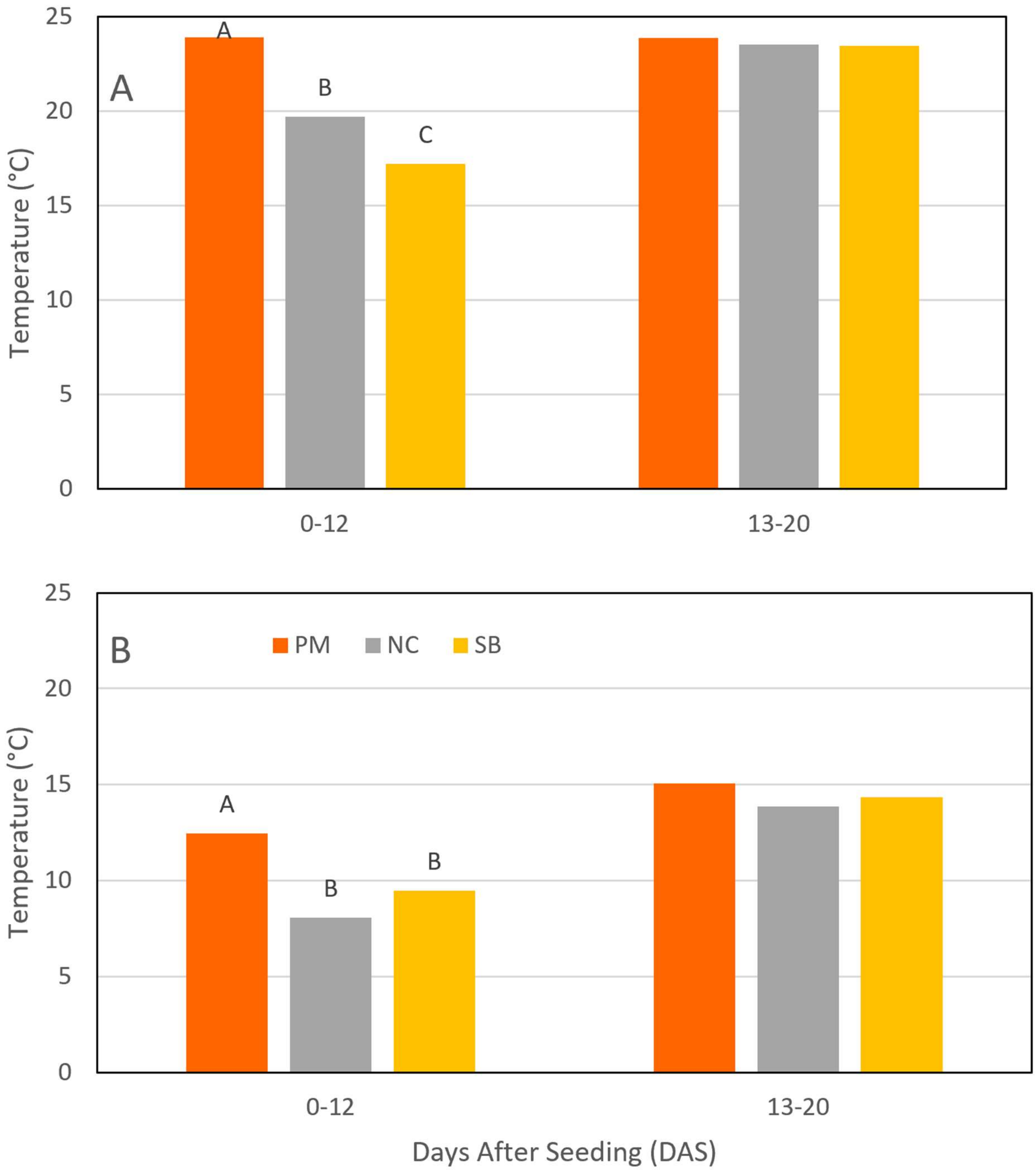

Figure 2.6. Soil-surface temperatures during day (top; A; 1000-1800 CST) and night (bottom; B; 2200-0600 CST) in both trials. Hourly temperature measurements were averaged over the early (0 to 6 DAS) and late (7 to 12 DAS) periods with covers installed, and the first 8 days after covers were removed (13 to 20 DAS). Treatments included a PM (Polyester), SB (Straw), and NC for the control (No Cover). Within each measurement period, means with no letters or the same letter are not significantly different at $\alpha = 0.05$.

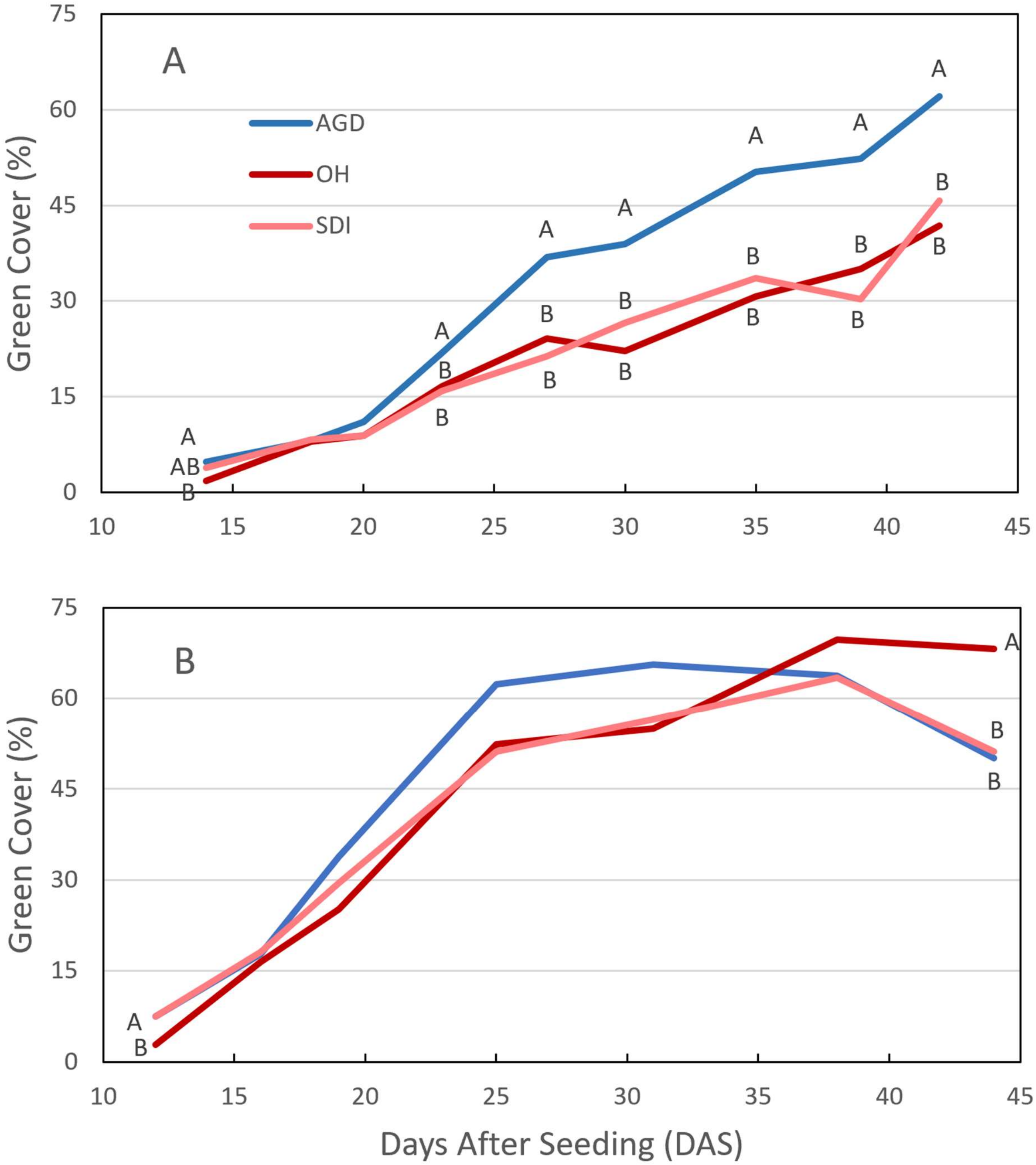

Figure 2.7. Green cover for each irrigation treatment on each measurement date during Trial 1(A) and Trial 2 (B). Irrigation treatments included aboveground drip (AGD), subsurface drip (SDI), and overhead (OH). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

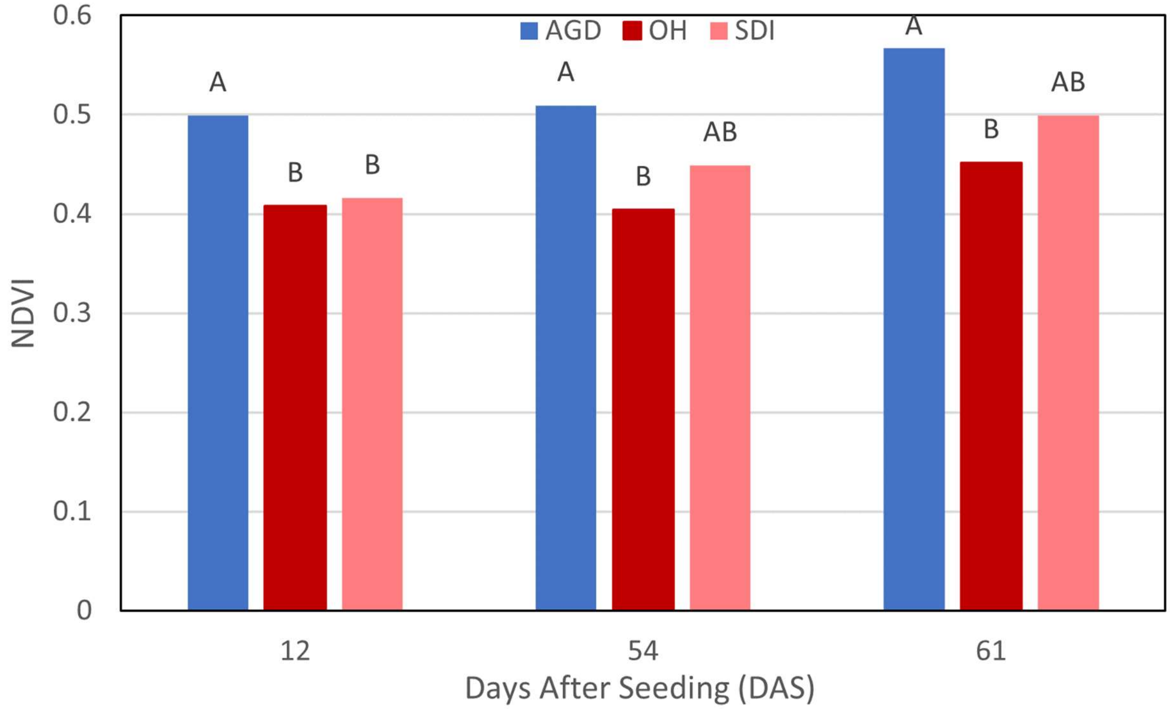

Figure 2.8. Ground-based normalized difference vegetation index (NDVI) for each treatment on each measurement date during Trial 1. Irrigation treatments included aboveground drip (AGD), subsurface drip (SDI), and overhead (OH). Within each measurement date, means with the same letter are not significantly different at $\alpha = 0.05$.

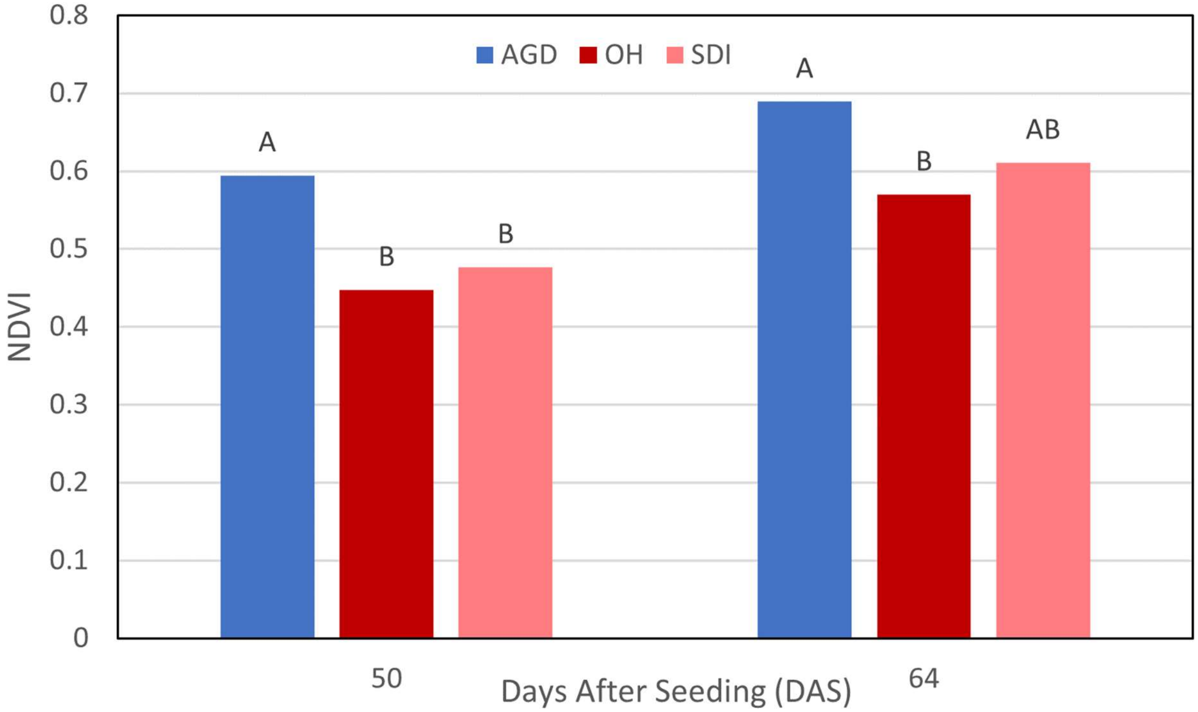

Figure 2.9. Drone-based normalized difference vegetation index (NDVI) for each treatment on each measurement date during Trial 1. Irrigation treatments included aboveground drip (AGD), subsurface drip (SDI), and overhead (OH). Within each measurement date, means with the same letter are not significantly different at α = 0.05.