The Impact of Cultural Control Strategies on Mitigating *Poa annua* Encroachment in a Mature Kentucky Bluegrass *(Poa pratensis)* Stand

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Introduction

Annual bluegrass (ABG) is a significant weed problem impacting golf courses, sports fields and other high quality turfgrass areas. This species is lighter in color, shallower rooted, less drought tolerant, less disease tolerant, less wear tolerant and very difficult to manage in the hot summer months compared to desirable turfgrasses (Branham, 1991). Its presence creates a nonuniform, mottled sward drastically reducing aesthetics and playing surface quality. Given the poor attributes of ABG, infested turfgrass stands often require more intensive management to maintain acceptable quality leading to more inputs and higher costs (McCullough et al., 2010). This aggressive, highly adaptive species has proven to be an extreme challenge for turfgrass managers to mitigate and/or control. Therefore, employing a multifaceted approach that encompasses a specific combination of several strategies including cultural, preemergent products, post emergent products, and plant growth regulators may be the best way to give the desirable species a competitive, long-term advantage.

Cultural practices such as clipping collection, have been shown to influence or potentially influence ABG encroachment, particularly when seedheads are present on ABG plants (Carroll et al., 2021). Returning clippings increased ABG 12% over plots in which clippings were removed and removing clippings reduced the number of viable ABG seeds in the soil by 60% in a mixed stand of ABG and creeping bentgrass (CBG) (Gaussoin and Branham, 1989).

Core cultivation is a cultural practice commonly utilized on recreational fields and golf courses to reduce compaction and improve turfgrass quality (Carrow et al., 1987; Dunn et al., 1995). *Poa annua* has been shown to tolerate compacted soil well (Warwick, 1979). However, relieving compaction through cultivation and the effect on *Poa annua* cover, is largely unknown. One study revealed that core cultivation paired with overseeding, reduced *Poa annua* in a bentgrass green (Morgan et al., 1965).

Most of the previous research related to the effects of clipping management and cultivation on *Poa annua* have been conducted on turfgrass with established infestations of *Poa annua*. This research aims to evaluate how these cultural practices effect the establishment of *Poa annua* in a mature Kentucky bluegrass *(Poa pratensis)* turfgrass stand with no *Poa annua*. This research was designed to assess the effect of cultivation type, cultivation timing and clipping management on (i) *Poa annua* cover, (ii) turfgrass quality and (iii) percent green cover.

Materials and Methods

A field study was initiated at the University of Connecticut Plant Science Research and Education Facility in Storrs, CT (41º 47' 44.9268" N, 72º 13'46.8156" W). The study area was sodded on 8 Sept 2020, over an area that was previously maintained as a *Poa annua* putting green on a Paxton, fine sandy loam soil (coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts). Glyphosate was applied to the *Poa annua* putting green and 7d later, a blec machine was then used to prepare the area. The sod was a Kentucky bluegrass *(Poa pratensis)* blend of 'Bluenote' 25%, 'Legend' 25%, 'Ginney II' 20%, 'Princeton P-105' 20%, and 'Bolt' 10%, that was originally seeded in Sept 2019 at Tuckahoe Farms (Hammonton, NJ).

The study was set out in a split plot design arranged as a 2×2×4 factorial with three replicates. Individual plots measured 1.8m×2.4m. The main plot factor, cultivation season, had two levels: fall cultivation and spring cultivation. Each main plot factor was split by clipping management (clippings returned or collected). Each individual plot was randomized by cultivation type: hollow tine cores returned (HTCR), hollow tine cores harvested (HTCH), solid tine cultivation (STC) and no cultivation (none). Hollow and solid tines were 5/8" in diameter, spaced 1.5" apart set to a 3" depth on a Toro ProCore 648 Aerator (The Toro Company, Bloomington, Minnesota). In 2020, cultivation treatments occurred on 23 (HTCR and HTCH) and 24 (STC) October. In 2021, spring cultivation treatments occurred on 1 (STC) and 6 (HTCR and HTCH) May and fall cultivation treatments on 19 (HTCR and HTCH) and 22 (STC) October. In 2022, spring cultivation treatments occurred on 13 May (all) and fall cultivation treatments occurred on 20 (HTCH and HTCR) and 21 (STC) October. The cores in the HTCR plots were mulched using a 22" rotary push mower after 2 days drying on surface of the turfgrass. The cores in the HTCH plots were removed by using a leaf rake once the cultivation was completed.

The sod was originally maintained at 7.6cm at the time of installation, but was maintained at 3.2cm for the study. Mowing was completed as needed to remove no more than 1/3rd of the foliage. In 2020, a starter fertilizer (16-25-12) (Lebanon Turf, Lebanon, PA) was applied at a rate of 0.5 lb N 1000ft $^{-2}$ using a broadcast spreader on 29 Sept and 24 Oct 2020, for a total of 1.6 lbs P_2O_5 1000ft $^{-2}$ and 0.8 lbs K_2O 1000ft $^{-2}$. The starter fertilizer contained 3.3% slowly available N from methylene urea. In 2021, the same 16-25-12 fertilizer was applied again at the same rates on 12 May and a complete fertilizer (15-2-8) (Lebanon Turf, Lebanon, PA) with 8.5% slowly available N from methylene urea and biosolids was applied at a rate of 1 lb N 1000ft $^{-2}$ and 0.5 lb K_2O 1000ft $^{-2}$ was applied on 10 June, 9 Aug, 17 Sept and 17 Oct. A combination of 1.44g a.i. azoystrobin and 0.03g a.i. acibenzolar S-methyl was applied on 16 Sept 2020 at a rate of 2.9oz 1000ft $^{-2}$. Fungicide was applied using a bike sprayer (custom fabricated) with 1 gal 1000ft $^{-2}$ nozzles at 40 psi. The entire research area was subjected to simulated athletic field traffic using a Brinkman Traffic Simulator (BTS) 2x week^{-1} April through November 2021. One traffic event consisted of two passes with BTS varying direction for each pass. Traffic simulation frequency increased to 3x week^{-1} beginning in May 2022.

Percent *Poa annua* cover was collected 5 May 2022 and 11 Nov 2023. Turfgrass quality was qualitatively assessed on a bi-weekly basis based on a visual rating scale (1=brown dead turfgrass plants; 9=darkest green densest turfgrass stand). Percent *Poa annua* cover was quantified using the line intersect method using two grids measuring 0.6m×1.7m with 240 intersections on each grid (480 intersections total) and each intersection spaced 6.3cm apart (Hoyle et. al, 2013). Percent *Poa annua* cover was calculated by dividing the sum of intersections aligning with *Poa annua* in the canopy by the total number of intersections and multiplying by 100. Percent green cover was analyzed on a bi-weekly basis in 2021 and 2022. Digital image analysis (DIA) (Karcher and Richardson, 2005; Richardson et. al, 2001) was used to calculate percent cover and dark green color index (DGCI) based on a digital image taken in a controlled light environment (Karcher and Richardson, 2003).

An analysis of variance was completed to test for significant treatment effects ($P \leq 0.05$) using the glimmix procedure in SAS statistical software 9.4 (SAS Institute, 2013). When significant source effects were obtained, means were separated using Fisher's least significant difference test. Data were tested for violations of assumptions for parametric analyses (normality of residuals, homogeneity of variance and non-additivity). Most dependent variables violated assumptions of the additive model and normality. Percent *Poa annua* cover, percent cover and quality were either transformed by the arcsine, square root or $\log_{10}$ transformation, if necessary, prior to statistical analysis. The analysis of variance and Fisher's means separations test were based on the transformed data, and the means were converted back to original scale for the results.

Results

Percent Poa annua Cover

2022 and 2023

Significant differences in percent *Poa annua* cover were observed in cultivation season (CS) and cultivation type (CT) as main effects (Table 1). There was also significant interaction between CS and CT on 5 May 2022 and 21 November 2023 (Table 1).

In 2022, this interaction revealed significantly less *Poa annua* cover with hollow tine cores harvested (HTCH) and hollow tine cores returned (HTCR) cultivation when implemented in spring compared to the fall (Figure 1). Solid tine cultivation (STC) and no cultivation resulted in very low percent *Poa annua* cover regardless of CS (Figure 1).

In 2023, this interaction also revealed significantly less *Poa annua* cover with spring HTCR cultivation compared to the fall (Figure 2). No cultivation and HTCH shared no differences between CS.

Percent Green Cover

2021

Significant differences in percent green cover resulted primarily from CS (Table 2). There was a significant interaction between CS and CT on all dates data were collected. The most pertinent interactions are described where appropriate.

The CS and CT interaction revealed that, in general, fall HTCR and HTCH resulted in greater percent green cover compared to spring cultivation (Figures 3 to 5). However, STC had similar percent green cover regardless of CS most data collection dates (Figures 4 and 5).

2022

Significant differences in percent green cover resulted primarily from CS main effect (Table 3). There was a significant interaction between CS and CT on 17 May 2022.

Similar to 2021, The CS and CT interaction revealed that fall HTCR and HTCH, resulted in greater percent green cover compared to spring, while STC had similar percent green cover regardless of CS (Figure 6).

Turfgrass Quality

2021

Significant differences in turfgrass quality resulted primarily from CS main effects (Table 4). There was a significant interaction between CS and CT on 16 June 2021 and 1 August 2021 (Table 4).

The CS and CT interaction on 16 June 2021 revealed that fall STC results in higher quality compared to the spring (Figure 7). Quality ratings were similar regardless of the season for HTCR, HTCH and no cultivation (Figure 7).

The CS and CT interaction on 1 August 2021 revealed that fall HTCR results in higher quality compared to the spring (Figure 8). Quality ratings were similar regardless of the season for HTCH, STC and no cultivation (Figure 8).

The CS main effect observed on 23 June 2021 and 13 August 2021 revealed that fall cultivation resulted in higher quality rating compared to the spring (Table 4).

2022

Significant differences in turfgrass quality were observed primarily as main effects (Table 5). There was a significant CS and CT interaction 17 May 2022 and 10 November 2022, a significant CT and CM interaction 2 October 2022, and a significant CS, CT and CM interaction 16 June 2022 and 15 August 2022 (Table 5). Main effects are described where appropriate.

Cultivation season main effect was significant on 16 October 2022 and revealed that spring cultivation resulted in higher turfgrass quality ratings compared to fall cultivation (Table 5). Cultivation type main effect was significant on 15 July 2022 and revealed that HTCR and HTCH resulted in higher turfgrass quality ratings compared to STC and no cultivation (Table 5). Clipping management main effects were significant on 1 May 2022 and 1 June 2022. These main effects revealed that returning clipping resulted in higher turfgrass quality compared to collecting clippings (Table 5).

The CS and CT interaction on 17 May 2022 showed that fall HTCH results in higher quality compared to spring (Figure 9). Quality ratings were similar regardless of the season for HTCR, STC and no cultivation (Figure 9). The CS and CT interaction on 10 November 2022 revealed that spring HTCR, HTCH and STC resulted in higher quality ratings compared to the fall (Figure 10). No cultivation had similar quality ratings regardless of the season (Figure 10).

The CT and CM interaction on 2 October 2022 revealed that HTCH and STC resulted in higher quality ratings when clippings were returned, while clipping management did not affect turfgrass quality rating for HTCR and no cultivation (Figure 11).

Tables

Table 1. Effect of cultivation season, cultivation type and clipping management on percent *Poa annua* cover

Main Effects	5 May 22	21 Nov 23
Cultivation Season	% *Poa annua* cover	
Spring	1.0 b[a]	16.7 b
Fall	1.4 a	33.6 a
Cultivation Type[b]		
HTCR	1.5 a	29.7 a
HTCH	1.2 ab	28.7 a
STC	1.1 b	24.6 ab
None	1.0 b	17.7 b
Clipping Management		
Collected	1.2 a	23.7 a
Returned	1.2 a	26.7 a
Variation Source	-----------ANOVA----------	
Cultivation Season (CS)	***	***
Cultivation Type (CT)	**	*
Clipping Management (CM)	NS	NS
CS × CT	***	**
CS × CM	NS	NS
CT × CM	NS	NS
CS × CT × CM	NS	NS

Note: Comparison is based on quantitative weed counts with 2 grids with 240 intersections each (480 intersections in total)

[a]Means in columns followed by the same letter, within each main effect, are not significantly different according to Fishers LSD *($P<0.05$)*

[b]HTCR: Hollow tine cultivation with cores returned, HTCH: Hollow tine cultivation with cores removed, STC: Solid tine cultivation, None: No cultivation.

Table 2. Effect of cultivation season, cultivation type and clipping management on percent green cover, 2021.

Main Effects	9 June	16 June	23 June	13 Sep	1 Oct
Cultivation Season	---------------------------% cover-------------------------				
Spring	89.5 b[a]	96.5 a	97.0 b	93.2 a	96.7 a
Fall	94.0 a	97.7 a	97.6 a	93.8 a	97.1 a
Cultivation Type[b]					
HTCR	91.2 a	97.1 a	97.0 a	94.8 a	97.3 a
HTCH	90.9 a	96.9 a	97.4 a	92.2 a	96.3 a
STC	93.0 a	97.5 a	97.4 a	94.5 a	97.4 a
None	91.7 a	97.0 a	97.4 a	92.5 a	96.7 a
Clipping Management					
Collected	91.3 a	96.8 a	97.3 a	92.4 b	96.6 a
Returned	92.1 a	97.4 a	97.3 a	94.6 a	97.2 a
Variation Source		-----------ANOVA----------			
Cultivation Season (CS)	*	NS	**	NS	NS
Cultivation Type (CT)	NS	NS	NS	NS	NS
Clipping Management (CM)	NS	NS	NS	*	NS
CS × CT	**	*	***	*	*
CS × CM	NS	NS	NS	NS	NS
CT × CM	NS	NS	NS	NS	NS
CS × CT × CM	NS	NS	NS	NS	NS

[a]Means in columns followed by the same letter, within each main effect, are not significantly different according to Fishers LSD *($P<0.05$)*

[b]HTCR: Hollow tine cultivation with cores returned, HTCH: Hollow tine cultivation with cores removed, STC: Solid tine cultivation, None: No cultivation.

Table 3. Effect of cultivation season, cultivation type and clipping management on percent green cover, 2022.

Main Effects	1 May	17 May	2 June	16 June	29 June
Cultivation Season	----------------------------------	-% cover-	-------------------------------		
Spring	93.7 a[a]	96.2 b	97.6 a	93.1 a	93.6 a
Fall	94.5 a	98.3 a	98.0 a	92.7 a	91.2 a
Cultivation Type[b]					
HTCR	95.1 a	97.2 a	97.8 a	93.4 a	92.4 a
HTCH	93.8 a	96.2 a	97.6 a	93.5 a	92.0 a
STC	93.3 a	97.5 a	97.9 a	92.2 a	92.3 a
None	94.0 a	98.1 a	98.0 a	92.6 a	92.8 a
Clipping Management					
Collected	93.4 a	97.3 a	97.7 a	93.1 a	92.4 a
Returned	94.7 a	97.2 a	98.0 a	92.8 a	92.4 a
Variation Source		------------------------	-ANOVA-	-------------------	
Cultivation Season (CS)	NS	**	NS	NS	NS
Cultivation Type (CT)	NS	NS	NS	NS	NS
Clipping Management (CM)	NS	NS	NS	NS	NS
CS × CT	NS	**	NS	NS	NS
CS × CM	NS	NS	NS	NS	NS
CT × CM	NS	NS	NS	NS	NS
CS × CT × CM	NS	NS	NS	NS	NS

[a]Means in columns followed by the same letter, within each main effect, are not significantly different according to Fishers LSD *($P<0.05$)*

[b]HTCR: Hollow tine cultivation with cores returned, HTCH: Hollow tine cultivation with cores removed, STC: Solid tine cultivation, None: No cultivation.

Table 4. Effect of cultivation season, cultivation type, and clipping management on turfgrass quality, 2021.

Main Effects	9 June	16 June	23 June	7 July	1 August	13 August	16 November
Cultivation Season		----------Quality Rating----------					
Spring	5.5 a[a]	5.5 a	5.5 b	6.0 a	5.3 b	5.2 b	4.9 a
Fall	5.8 a	5.8 a	6.1 a	6.0 a	5.6 a	5.5 a	4.8 a
Cultivation Type[b]							
HTCR	5.7 ab	5.6 a	5.9 a	6.0 a	5.5 ab	5.5 a	5.0 a
HTCH	5.5 b	5.5 a	5.6 a	6.0 a	5.5 ab	5.3 a	4.8 a
STC	5.9 a	5.9 a	5.7 a	6.0 a	5.2 b	5.2 a	4.8 a
None	5.5 ab	5.6 a	5.9 a	6.0 a	5.6 a	5.5 a	5.0 a
Clipping Management							
Collected	5.7 a	5.5 a	5.8 a	6.0 a	5.4 a	5.2 a	4.8 a
Returned	5.6 a	5.8 a	5.7 a	6.0 a	5.5 a	5.5 a	4.9 a
Variation Source			----------ANOVA----------				
Cultivation Season (CS)	NS	NS	**	NS	*	*	NS
Cultivation Type (CT)	NS	NS	NS	NS	NS	NS	NS
Clipping Management (CM)	NS	NS	NS	NS	NS	NS	NS
CS × CT	NS	*	NS	NS	*	NS	NS
CS × CM	NS	NS	NS	NS	NS	NS	NS
CT × CM	NS	NS	NS	NS	NS	NS	NS
CS × CT × CM	NS	NS	NS	NS	NS	NS	NS

Note: Quality Ratings: 1, dead and/or brown turf, high weed cover; 6, minimum acceptable quality; 9, optimum quality

[a]Means in columns followed by the same letter, within each main effect, are not significantly different according to Fishers LSD *(P<0.05)*

[b]HTCR: Hollow tine cultivation with cores returned, HTCH: Hollow tine cultivation with cores removed, STC: Solid tine cultivation, None: No cultivation.

Table 5. Effect of cultivation season, cultivation type and clipping management on turfgrass quality, 2022.

Main Effects	1 May	17 May	1 June	16 June	29 June	15 July	15 Aug	14 Sep	28 Sep	2 Oct	16 Oct	10 Nov
Cultivation Season	---Quality Rating---											
Spring	4.2 a[a]	4.8 a	5.1 a	5.3 a	5.7 a	5.4 a	5.1 a	6.2 a	5.3 a	5.3 a	5.3 a	4.8 a
Fall	4.3 a	5.1 a	5.3 a	5.4 a	5.8 a	5.5 a	5.2 a	5.9 a	5.0 a	5.0 b	4.7 b	4.2 b
Cultivation Type[b]												
HTCR	4.3 a	5.0 a	5.3 a	5.6 a	5.9 a	5.8 a	5.0 a	5.9 a	5.4 a	5.3 a	5.0 a	4.5 a
HTCH	4.3 a	4.9 a	5.1 a	5.5 ab	5.9 a	5.7 a	5.2 ab	6.2 a	5.2 a	5.0 a	4.9 a	4.5 a
STC	4.3 a	5.1 a	5.1 a	5.2 ab	5.6 a	5.2 b	5.0 b	6.2 a	5.2 a	5.2 a	5.1 a	4.6 a
None	4.1 a	5.0 a	5.2 a	5.1 b	5.6 a	5.2 b	5.0 b	5.9 a	5.0 a	5.1 a	4.9 a	4.5 a
Clipping Management												
Collected	4.1 b	4.8 b	5.0 b	5.3 a	5.7 a	5.4 a	5.0 b	5.9 a	5.0 a	5.0 b	4.9 a	4.4 a
Returned	4.4 a	5.2 a	5.3 a	5.4 a	5.8 a	5.5 a	5.2 a	6.2 a	5.3 a	5.3 a	5.1 a	4.6 a
Variation Source	---ANOVA---											
Cultivation Season (CS)	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	**	***
Cultivation Type (CT)	NS	NS	NS	NS	NS	*	**	NS	NS	NS	NS	NS
Clipping Management (CM)	*	*	*	NS	NS	NS	*	NS	NS	*	NS	NS
CS × CT	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
CS × CM	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT × CM	NS	NS	NS	NS	NS	NS	*	NS	NS	*	NS	NS
CS × CT × CM	NS	NS	NS	*	NS	NS	**	NS	NS	NS	NS	NS

Note: Quality Ratings: 1, dead and/or brown turf, high weed cover; 6, minimum acceptable quality; 9, optimum quality

[a]Means in columns followed by the same letter, within each main effect, are not significantly different according to Fishers LSD *(P<0.05)*

[b]HTCR: Hollow tine cultivation with cores returned, HTCH: Hollow tine cultivation with cores removed, STC: Solid tine cultivation, None: No cultivation.

Figures

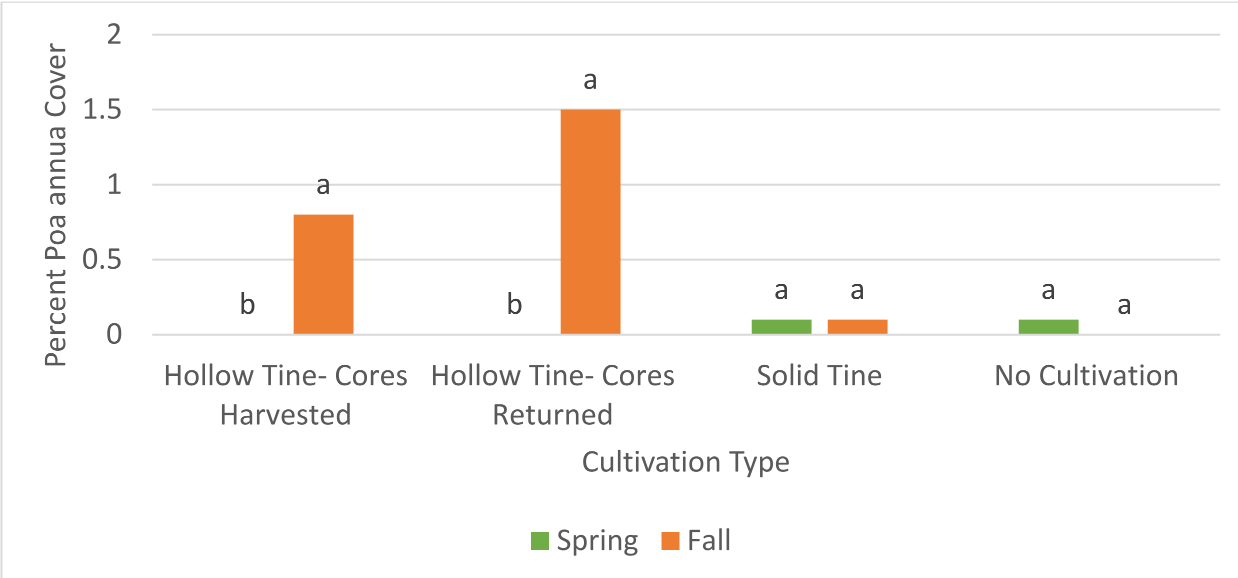

Figure 1. Interaction of cultivation season x cultivation type on percent *Poa annua* cover May, 2022.

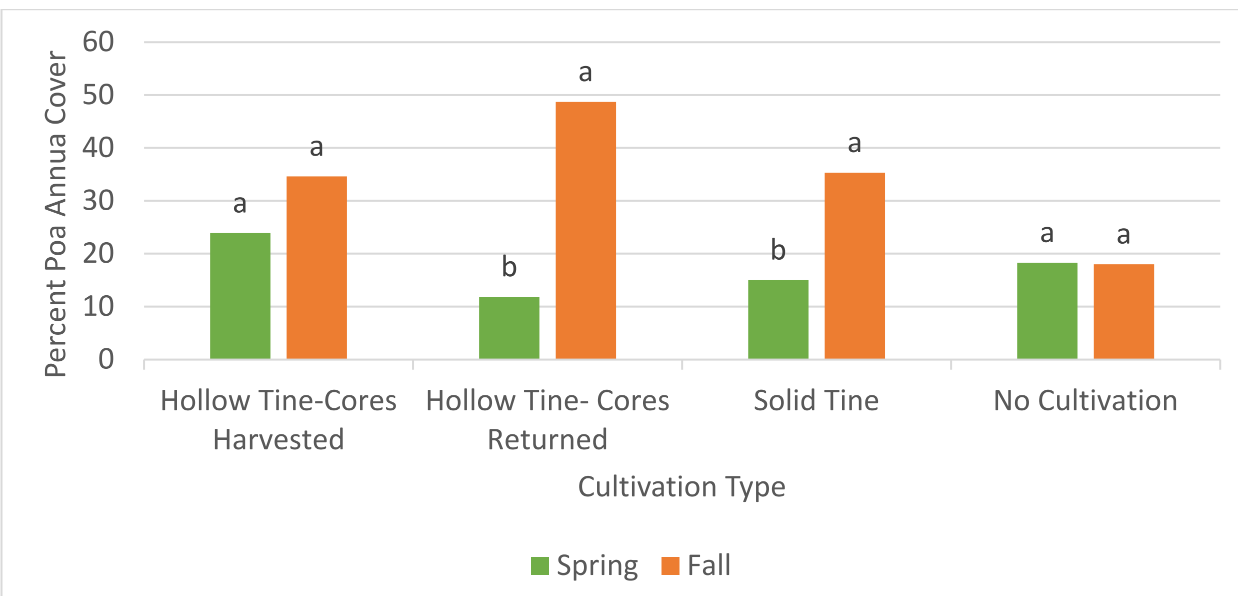

Figure 2. Interaction of cultivation season x cultivation type on percent *Poa annua* cover November, 2023.

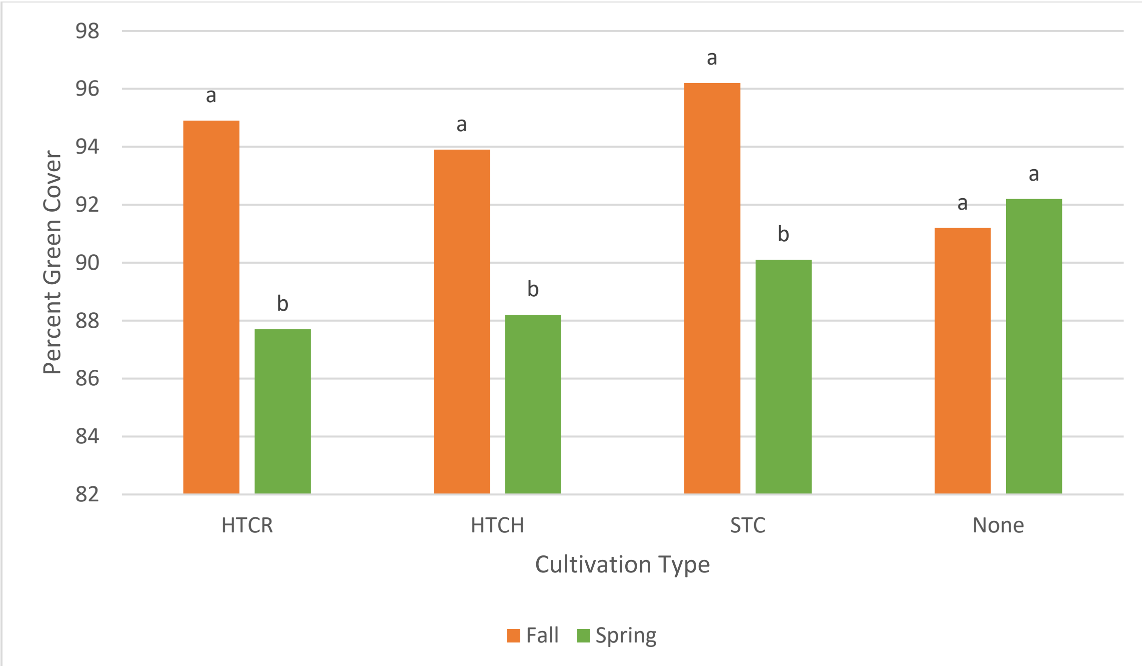

Figure 3. Interaction of cultivation season x cultivation type on percent green cover 9 June 2021.

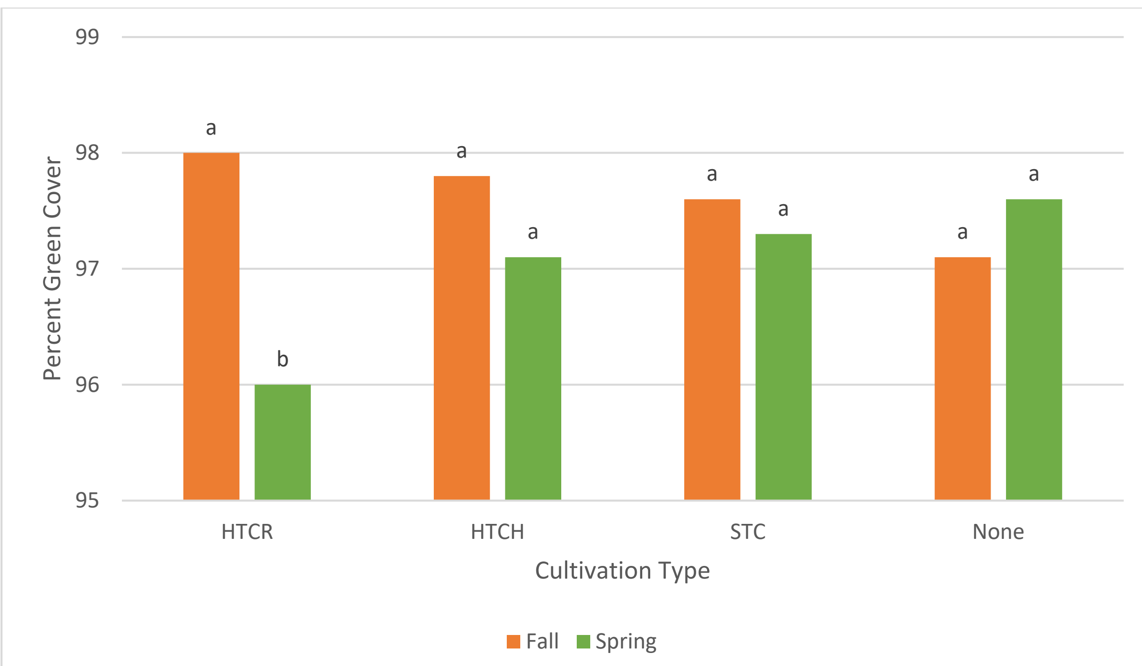

Figure 4. Interaction of cultivation season x cultivation type on percent green cover 23 June 2021.

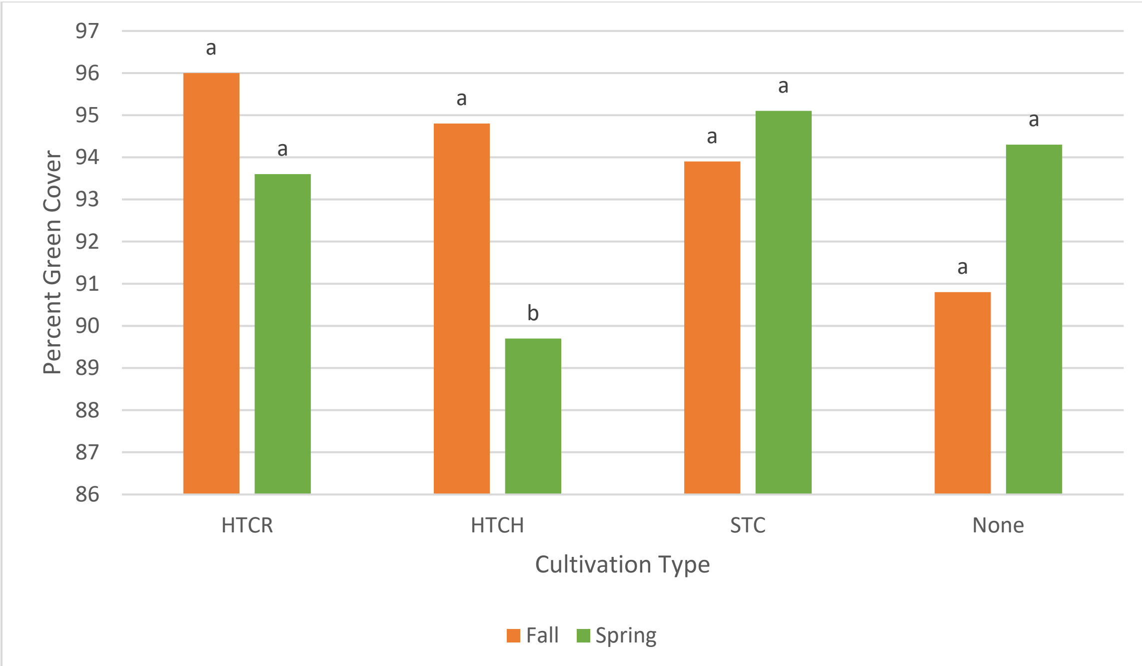

Figure 5. Interaction of cultivation season x cultivation type on percent green cover 13 September 2021.

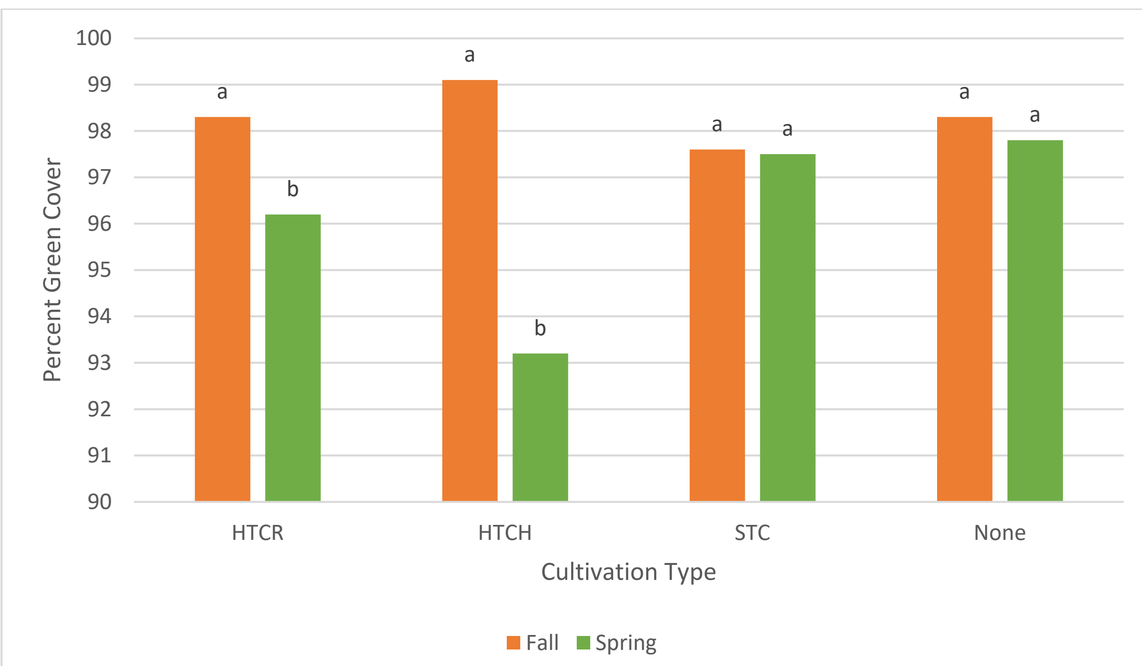

Figure 6. Interaction of cultivation season x cultivation type on percent green cover 17 May 2022.

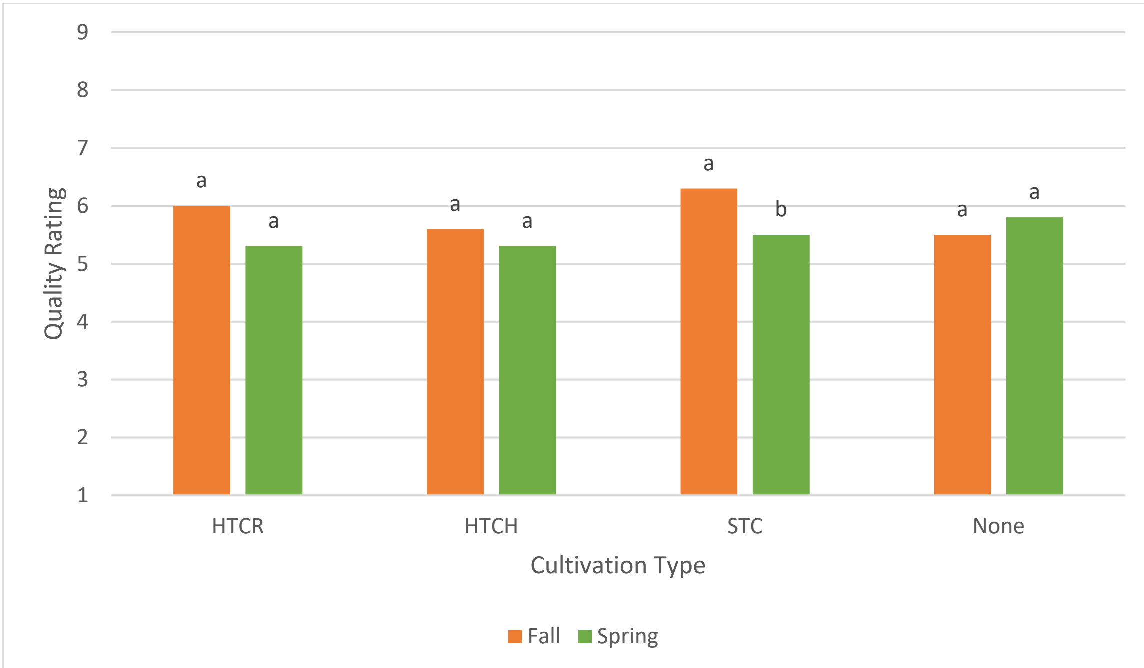

Figure 7. Interaction of cultivation season x cultivation type on turfgrass quality 16 June 2021.

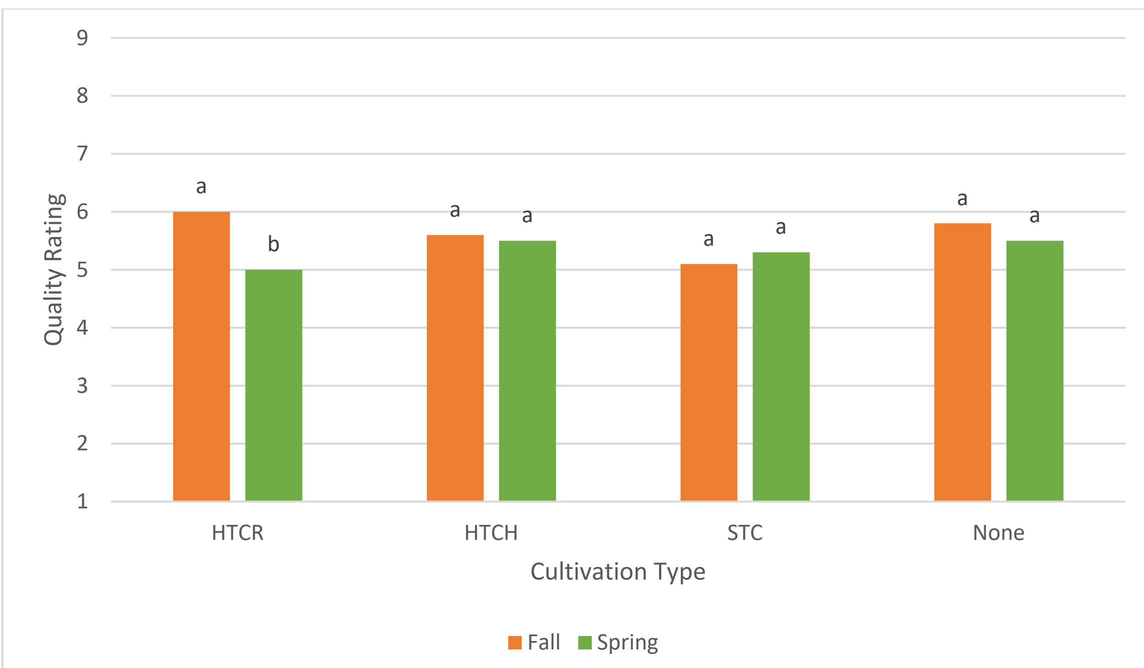

Figure 8. Interaction of cultivation season x cultivation type on turfgrass quality 1 August 2021.

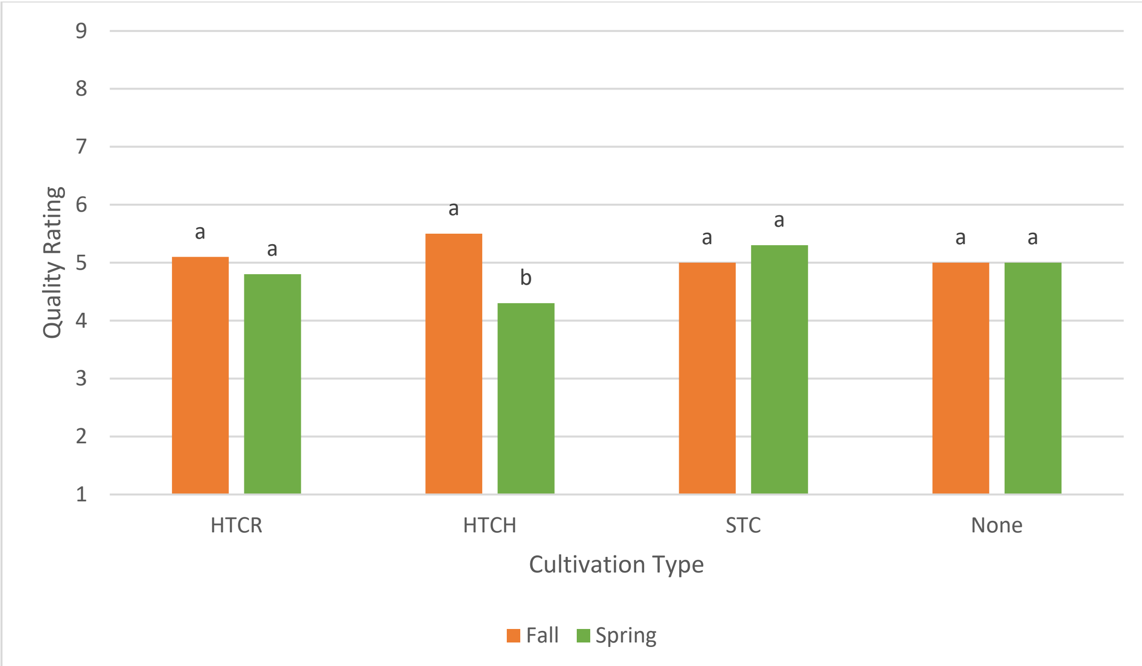

Figure 9. Interaction of cultivation season x cultivation type on turfgrass quality 17 May 2022.

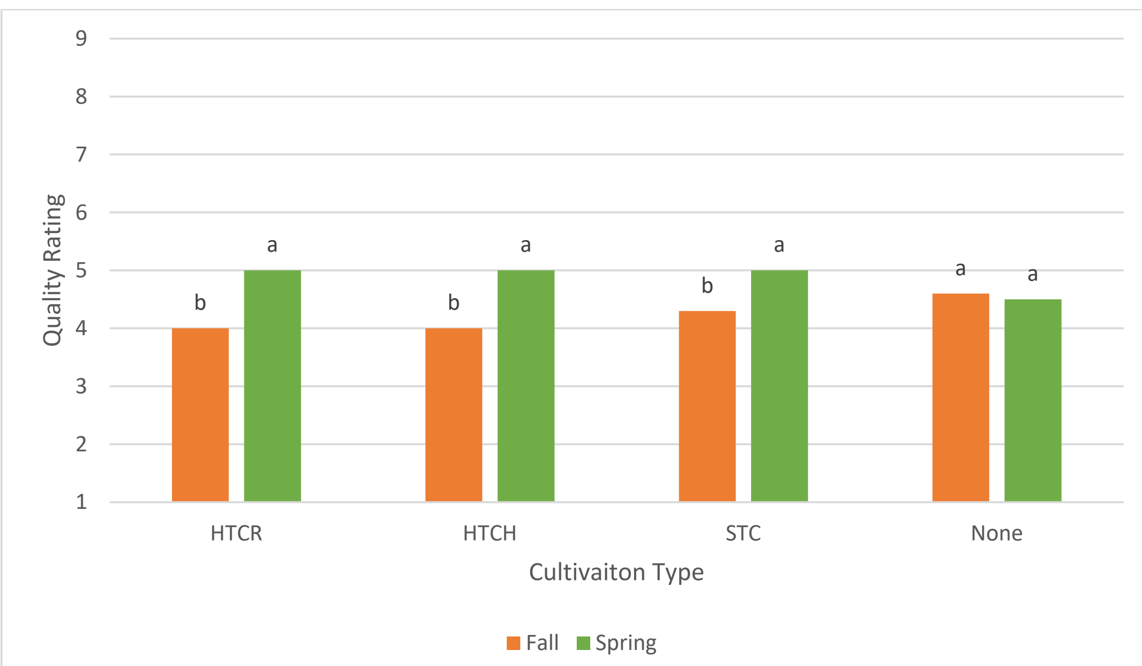

Figure 10. Interaction of cultivation season x cultivation type on turfgrass quality 10 Nov 2022.

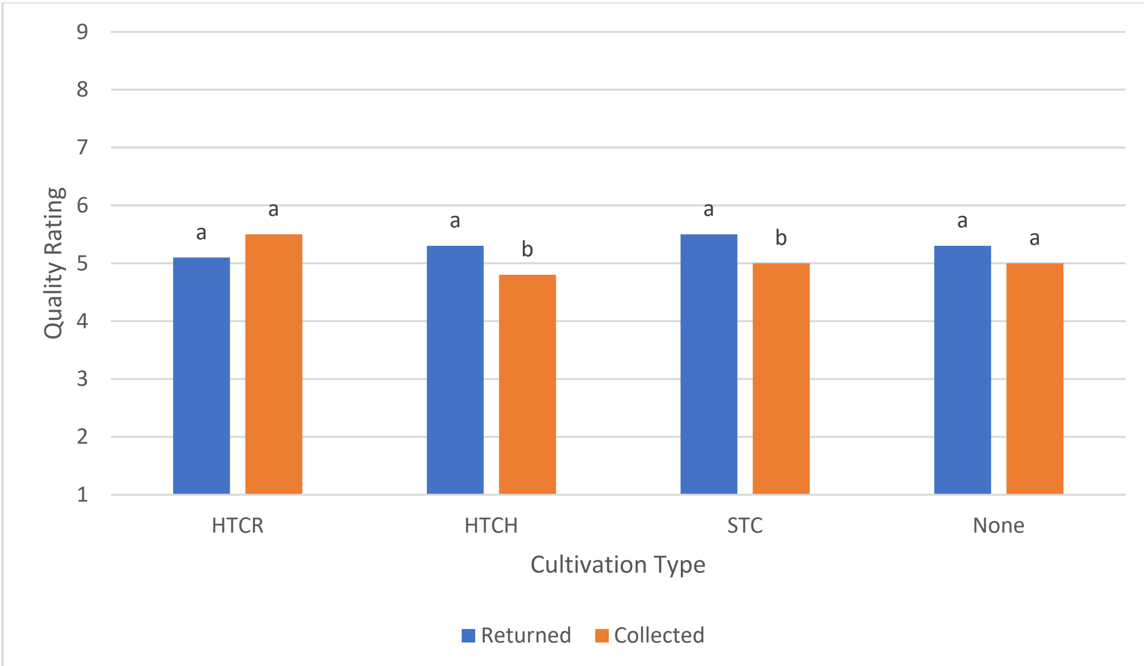

Figure 11. Interaction of cultivation type x clipping management on turfgrass quality 2 Oct 2022.

Discussion and Conclusion

The ability or inability of *Poa annua* to infest an established Kentucky bluegrass stand is dependent upon the season in which cultivation occurs, the type of cultivation and whether clippings are collected or returned to the turfgrass. The primary objective of this research was to identify these key factors or which combination of these factors that the turfgrass manager can implement to minimize *Poa annua* infestation in an established Kentucky bluegrass stand.

In general, the data indicates that cultivation practices performed in the spring will result in less ABG encroachment, particularly with HTCR and STC. If cultivating in the fall, cores should be harvested. It is theorized that fall cultivation should be avoided in the fall when *Poa annua* germinates (Dernoeden, 2013). However, previous research has observed the timing of hollow tine cultivation has no effect on *Poa annua* cover (Patton et al., 2019).

Collecting clippings had no effect on *Poa annua* cover. However, there are many reports that the removal of clippings has typically reduced *Poa annua* cover in both Kentucky bluegrass (*Poa pratensis*) and creeping bentgrass (*Agrostis stolonifera*) stands (Beard et al., 1978; Gaussoin et al., 1989; Pierce et al., 1987). This was most likely due to the short duration of the study and low *Poa annua* populations of the sod used to establish the study area.

Fall cultivation resulted in greater percent green cover compared to Spring cultivation in 2021 and 2022. There was some indication that fall cultivation resulted in better turfgrass quality in 2021 with STC and HTCR. Conversely, there was some indication that spring cultivation resulted in better turfgrass quality in 2022 regardless of cultivation type. Results from previous research indicate that turfgrass quality declines when cultivation occurs from June through August (Atkinson et al., 2012)

Some differences in clipping management were observed at the end of the 2022 season, where clippings returned resulted in higher quality ratings in HTCH and STC plots.

Based upon the results of this research, turfgrass managers desiring minimal *Poa annua* infestation should consider cultivating in the spring, regardless of cultivation type. Cultivating in the fall resulted in greater percent green cover but also greater *Poa annua* cover but did result in greater percent green cover. Due to the short duration of the study, *Poa* *annua* cover was relatively low and further long-term investigation is required.

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