Cultural and Chemical Practices for Quality Improvement of Overseeded Bermudagrass [Cynodon dactylon (L.) Pers. × C. transvaalensis Burtt-Davy] and Annual Bluegrass (Poa annua L.) Suppression

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Abstract

Dormant bermudagrass (Cynodon dactylon (L.) Pers. × C. transvaalensis Burtt-Davy) is overseeded with perennial ryegrass (Lolium perenne L.) to maintain green color through the fall and winter. Annual bluegrass (Poa annua L.) control is critical for overseeding success, as this weed can greatly decrease aesthetic quality and playability of turfgrass due to excessive seedhead production. Research was conducted to evaluate the influence of pre-seeding cultural practices (scaping, solid-tine aerification, vertical mowing, and vertical mowing plus scalping) on overseeding establishment. The effect of increasing overseeding rates of perennial ryegrass (111, 222, 444, and 888 kg pure live seed·ha⁻¹; 100, 200, 400, and 800 lb·A⁻¹) and roughstalk bluegrass (Poa trivialis L.) (55, 111, and 222 kg pure live seed·ha⁻¹; 50, 100, and 200 lb·A⁻¹) on annual bluegrass populations was also investigated. Additionally, plant growth regulators (PGRs) were evaluated for annual bluegrass seedhead suppression and turf injury. Mefluidide at 0.056 kg ae·ha⁻¹ (0.05 lb ae·A⁻¹), and paclobutrazol, flurprimidol, trinexapac-ethyl, and trinexapac-ethyl plus ethephon at 0.28, 0.42, 0.382, and 0.095 plus 3.82 kg ai·ha⁻¹ (0.25, 0.37, 0.34, 0.085 plus 3.4 lb ai·A⁻¹), respectively, were applied twice, sequentially with a four-week interval. Contrary to previous research, pre-seeding cultural practices did not improve overseeding success. Annual bluegrass density decreased with increasing perennial ryegrass overseeding rates from 50% in the non-overseeded to 14 to 17% when overseeded with rates up to 222 kg pure live seed·ha⁻¹, and 4 to 8% when overseeded with rates between 444 and 888 kg pure live seed·ha⁻¹. Roughstalk bluegrass overseeded reduced annual bluegrass density from 50% in the non-overseeded, to 7 to 13% when overseeded with 55, 111, or 222 kg pure live seed·ha⁻¹, regardless of the overseeding rate. Overseeding bermudagrass with roughstalk bluegrass or perennial ryegrass increased turfgrass green cover during winter, especially 100 days after seeding. Paclobutrazol, flurprimidol, and trinexapac-ethyl were successful at suppressing annual bluegrass seedheads and were not injurious to perennial ryegrass. Mefluidide resulted in efficient annual bluegrass seedhead suppression; however, unacceptable turfgrass injury occurred in 2012.

Index words: overseeding; cultural practices; seedhead suppression; turfgrass density; annual bluegrass control; perennial ryegrass, roughstalk bluegrass.

Species used in this study: bermudagrass (Cynodon dactylon (L.) Pers × C. transvaalensis Burtt Davy); perennial ryegrass (Lolium perenne L.); roughstalk bluegrass (Poa trivialis L.); annual bluegrass (Poa annua L.).

Chemicals used in this study: diethanolamine salt of mefluidide (Embark 2S); paclobutrazol (Trimmit SC); flurprimidol (Cutless); trinexapac-ethyl (Primo Maxx); ethephon (Proxy).

Significance to the Horticulture Industry

Overseeding bermudagrass with cool-season grasses during the cold months is an input- and labor-demanding operation. Overseeding success is dependent on proper establishment of the desired cool-season species, suppression or control of annual bluegrass, and ideally, a quick, smooth spring transition back to bermudagrass. This study investigated alternative approaches for overseeding success and annual bluegrass suppression. Pre-seeding cultural practices did not enhance overseeding establishment or quality. Increasing seeding rates of perennial ryegrass (up to 444 kg·ha⁻¹ or 400 lb·A⁻¹) and roughstalk bluegrass (up to 111 kg·ha⁻¹ or 100 lb·A⁻¹) greatly enhanced turfgrass green cover and reduced annual bluegrass density. Aesthetic quality of overseeded perennial ryegrass can be further improved by seedhead suppression in annual bluegrass by paclobutrazol, flurprimidol, and trinexapac-ethyl.

Introduction

Overseeding bermudagrass turf with perennial ryegrass is a common practice in bermudagrass turf to overcome bermudagrass winter dormancy (Dudeck and Peacock 1980, Schmidt and Shoulders 1977, Turgeon 2012, Volterrani et al. 2004). Perennial ryegrass maintains many desirable characteristics through the winter such as rapid germination, dark green color, high turfgrass quality (Allen et al. 1993, Horgan and Yelverton 2001), and acceptable wear tolerance (Mazur and Wagner 1987, Landry 1993).

Previous research has demonstrated that seedbed preparation in overseeded turf to improve seed-soil contact is as crucial as in new or permanent turf. Common practices utili-
lized to enhance overseeding establishment include surface disturbance practices such as vertical mowing or aerification to aid in seed germination, as well as additional irrigation and fertility (Mazur and Rice 1999, Ward et al. 1974, Sifers and Beard 2001). Duble (1996) and Schmidt (1970) concluded that vertical mowing, scalping, and core aerification prior to seeding are beneficial for overseeing success. Controversially, aeration prior to overseeding, while increasing seed-soil contact (Beard 1973, DiPaola and Gilbert 1982), may result in poor germination pattern due to accumulation of seeds in the open holes (Watschke and Schmidt 1992). Thatch presence may also result in poor overseeding efficacy (Duble 1996). Perennial ryegrass seedlings that germinate in excessive thatch in bermudagrass are more prone to cold and wear damage than seedlings that germinate in the soil (Ward et al. 1974, Turgeon 2012). Furthermore, cultivation practices prior to overseeing may increase competition between bermudagrass and perennial ryegrass, impacting bermudagrass spring transition (Horgan and Yelverton 2001, Duble 1982, Ward et al. 1974).

Annual bluegrass is often cited as one of the most troublesome weeds in turfgrass (Beard et al. 1978, Christians 2006, Webster 2004, McElroy et al. 2011). Annual bluegrass is particularly problematic in overseeded bermudagrass, since many of the turfgrass management practices that help promote growth and development of the cool-season overseeded turfgrass also promote annual bluegrass growth and development.

Herbicide availability for annual bluegrass control in bermudagrass is limited when overseeing with perennial ryegrass is done. Additionally, annual bluegrass has evolved resistance to six different commonly used herbicide modes of action (Brosnan et al. 2012, Kelly et al. 1999, Heap 2014, McElroy et al. 2013). Future research on annual bluegrass control must, therefore, focus on alternatives to herbicides. Plant growth regulators (PGRs) are one such alternative. Use of PGRs employs a two-fold strategy: 1) reduce growth of annual bluegrass, allowing the oversown species to outcompete it, and 2) reduce or eliminate annual bluegrass seedhead production, which can visually mask the presence of that species as well as reduce the population in future years. Ethephon is commonly used for annual bluegrass seedhead suppression. Ethephon applied three times at 3.2 kg ai·ha⁻¹ (2.8 lb ai·A⁻¹) reduced annual bluegrass dry weight and quality compared to creeping bentgrass (Agrostis stolonifera L.) (Eggen et al. 1989). Another PGR, mefluhoide, has also been reported to effectively reduce annual bluegrass seedheads greater than 90% relative to nontreated; however, perennial ryegrass injury can occur (Neff et al. 1999, Watschke 1996). Paclobutrazol and flurprimidol have also been extensively researched for annual bluegrass control in creeping bentgrass putting greens. Johnson and Murphy (1995) reported paclobutrazol controlled annual bluegrass more efficiently than flurprimidol, but both can cause unacceptable creeping bentgrass injury. Paclobutrazol and flurprimidol suppressed annual bluegrass more successfully applied on a four-week schedule as opposed to a six-week schedule (Johnson and Murphy 1995, 1996).

With increasing herbicide resistance in weed species, alternative annual bluegrass management strategies in overseeded bermudagrass are needed. Our approach aimed to (i) assess impact of pre-seeding cultural practices on overseeding success and bermudagrass health, and (ii) evaluate overseeding rates and PGRs for annual bluegrass control/suppression in overseeded turf.

Materials and Methods

Three research projects, pre-seeding cultural practices, overseeding rate, and PGR evaluation, were conducted at three locations, as potential alternative management practices to herbicides. Research locations were: Auburn University Turfgrass Research and Education Center in Auburn, Alabama, USA, the University of California — Riverside Turfgrass Research Unit, Riverside, California, USA, and the University of Pisa Centre for Research on Turfgrass for Environment and Sports (CeRTES), in Pisa, Italy; all on mature stands of ‘Tifway’ bermudagrass. The Auburn soil type was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic, Typic Kanhapludult) with pH 6.2 and 2.1% organic matter. The Riverside soil type was a Henford fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthent) with pH 6.8 and 1.0% organic matter. The Pisa soil consisted of a calcareous fluvisoil (Coarse-silty, mixed, thermic, Xerochrome) with pH 7.7 and 1.8% organic matter.

Pre-seeding cultural practices. Cultural practices included scalping, solid-tine aerification, vertical mowing, and vertical mowing plus scalping. Cultivation methods on 3 by 2 m (10 by 6.5 ft) plots took place on September 1, 2011, and September 13, 2011, for Auburn and Pisa, respectively, 7 days prior to overseeding. Scalloping was initially done by reducing the mowing height from 1.5 to 0.3 cm (0.6 to 0.12 in) using a walk-behind reel mower (John Deere 20SR7, John Deere, Moline, IL). Scalloped plots were mowed three times at 0.3 cm (0.12 in) prior to overseeding. Clippings and excess debris were removed from all plots using a common leaf blower. After overseeding, mowing height was restored to 1.5 cm (0.6 in). Vertical mowing was done in two directions 7 days prior to overseeding, using a tractor-pulled unit (Amazone Groundkeeper GH 135, Falcon Agricultural Equipment (PTY) Ltd. Kwazulu-Natal, South Africa), with a blade depth of 5 mm (0.2 in) below mowing height, with debris removal. Solid-tine aerification was done using a tractor-pulled unit (Wiedenmann Terra Spike XP, Wiedenmann Ltd. Renfrew, Scotland), equipped with 12 mm (0.5 in) (Pisa) and 18 mm (0.7 in) (Auburn) diameter solid tines spaced at 10 by 10 cm (4 by 4 in), and depth 10 cm (4 in). A non-cultivated treatment was included as a control. Overseeding date was September 20, 2011. The Auburn overseeding trial utilized ‘TopGun II’ perennial ryegrass (Jacklin Seed by Symplot, Post Falls, ID). The Pisa overseeding trial consisted of a blend with 3 cultivars: ‘Gray Fox’, ‘Inspire’, and ‘Silver Dollar’ (Everris Italia, Treviso) in a 25-25-50 proportion on a percent basis. Perennial ryegrass was seeded with a drop spreader with a 1 m (3.3 ft) working width and a 12.5 g·m⁻² (0.0026 lb·ft⁻²) delivery rate, at 500 or 1,000 kg pure live seed·ha⁻¹ (445 or 890 lb·A⁻¹). Germination cloth (Agritn, Carreta Tessitura Snc. Vicenza, Italy) at 20 g·m⁻² (0.004 lb·ft⁻²) was used in Pisa to cover plots during germination, but was not utilized in Auburn. Four weeks prior to seeding, ammonium sulfate was applied to plots in Auburn and Pisa, providing 50 kg N·ha⁻¹ (44.5 lb·A⁻¹). Fertilization was performed again at seeding [ammonium sulfate, 50 kg N·ha⁻¹ (44.5 lb·A⁻¹); triple superphosphate, 100 kg P₂O₅·ha⁻¹ (89 lb·A⁻¹); potassium sulfate, 40 kg K₂O·ha⁻¹ (35.6 lb·A⁻¹)] in Pisa, and 100 kg
K₂O·ha⁻¹ (89 lb·A⁻¹) in Auburn, and in October, November, February, March, and April [ammonium sulfate, 50 kg N·ha⁻¹ (44.5 lb·A⁻¹)], providing a total of 250 kg N·ha⁻¹ (222 lb·A⁻¹). Irrigation provided adequate water during establishment and post-establishment periods. In the following spring, plots were allowed to transition naturally with no chemical or cultural intervention for perennial ryegrass removal. Experimental design was a strip-plot within a randomized complete block with 4 replications in both locations. Main and subplot treatments consisted of cultivation practices and overseeding rate, respectively. Turfgrass quality (TQ) was measured visually on a 1–9 scale in September and October 2011, and January and May 2012. TQ considered turfgrass cover and density of green, actively growing turfgrass (bermudagrass, perennial ryegrass, or a combination of both), and annual bluegrass infestation. Counts were performed during spring transition in April, May, and June 2012 on annual bluegrass, perennial ryegrass, and bermudagrass. Counts used a grid 1 by 1 m containing 25 intersections and 36 squares. The species that fell directly under each intersection were counted. Count data were converted to percentage by dividing the count number for the species by 25 (total number of grid intersections), therefore reflecting turfgrass density for the three species. Data were analyzed in SAS (SAS Institute Inc., Cary, NC) using PROC GLM and means were submitted to ANOVA and separated utilizing Fisher’s protected test at the α = 0.05 level.

Overseeding rate. Research was conducted to evaluate perennial ryegrass and roughstalk bluegrass overseeding rate in Tifway bermudagrass turf infested with annual bluegrass in Auburn (AL) and Riverside (CA). Seeding rates of Top Gun II perennial ryegrass were 111, 222, 444, and 888 kg pure live seed·ha⁻¹ (100, 200, 400, and 800 lb·A⁻¹). Seeding rates of ‘Havana’ roughstalk bluegrass (Jacklin Seed by Simplot; Boise, ID) were 55, 111, and 222 kg pure live seed·A⁻¹ (50, 100, and 200 lb·A⁻¹). A nontreated control was also included. Seeding rates were based on commonly used rates for golf course fairways and putting greens. Research was conducted as a randomized complete block designs with three (Auburn) and four replications (Riverside). Prior to the overseeding, bermudagrass was scalped by reducing the mowing height and for Riverside was October 7, 2011. Plots were fertilized using a formulated fertilizer (25N-4P-8K, Turf Special, Piedmont Fertilizer Company Inc. Opelika, AL) at the Auburn location 92, 120, and 150 DAS, providing 24 kg N·ha⁻¹ (21.3 lb·A⁻¹), 4 kg P₂O₅·ha⁻¹ (3.6 lb·A⁻¹), and 8 kg K₂O·ha⁻¹ (7.1 lb·A⁻¹) at each application. For the Riverside location, the formulation used was 15N-15P-15K (Compound Fertilizer, Granular. Agrium US Inc. Fresno, CA), providing 34 kg·ha⁻¹ (30 lb·A⁻¹) each of N, P₂O₅, and K₂O. Counts were taken 175 DAS for annual bluegrass within the turf system using a grid with 25 intersections. Annual bluegrass appearing directly under each intersection was counted. Count data were converted to a percentage relative to the nontreated mean, thus converting counts to percent cover for annual bluegrass. Percent green cover (100, 130, and 175 DAS) was also analyzed utilizing digital image analysis with SigmaScan (Systat Software Inc., Chicago, IL) according to Karcher and Richardson (2005). Hue values were 44 to 112 and saturation values were 30 to 100.

Data were analyzed in SAS using PROC GLIMMIX, and data were analyzed using ANOVA, with mean separation utilizing 95% confidence intervals with α = 0.05. Green cover data were analyzed in SAS, via PROC GLM, using a quadratic model for regression analysis, with significance level of P < 0.05. Means and fitted equations were plotted in SigmaPlot (SPSS Inc., Chicago, IL).

PGR seedhead suppression. Research was conducted to evaluate the use of PGRs for annual bluegrass seedhead suppression and turfgrass injury. Research was conducted only at the Auburn location and repeated in time at the 2010–2011 and 2011–2012 seasons. The research site consisted of a Tifway bermudagrass turf infested with annual bluegrass. The area was overseeded with Top Gun II perennial ryegrass at 440 kg pure live seed ha⁻¹ on October 3, 2010, and October 10, 2011. Plots were prepared, seeded, fertilized, and irrigated similarly to the seeding rate study. PGR treatments were: mefluvida (Embank 2S, PBI/Gordon Corporation, Kansas City, MO) at 0.056 kg ae·ha⁻¹ (0.05 lb ae·A⁻¹), paclobutrazol (Trimmit SC, Syngenta Crop Protection, Greensboro, NC) at 0.28 kg ai·ha⁻¹ (0.25 lb ai·A⁻¹), flurprimidol (Cutless, SePRO Corporation, Carmel, IN) at 0.42 kg ai·ha⁻¹ (0.37 lb ai·A⁻¹), trinexapac-ethyl (Primo Maxx, Syngenta Crop Protection, Greensboro, NC) at 0.38 kg ai·ha⁻¹ (0.34 lb ai·A⁻¹), and trinexapac-ethyl at 0.095 kg ai·ha⁻¹ (0.08 lb ai·A⁻¹) plus ethephon (Proxy, Bayer Environmental Science, Research Triangle Park, NC) at 3.82 kg ai·ha⁻¹ (3.4 lb ai·A⁻¹). All treatments were applied twice, with treatments spaced four weeks apart. Initial treatments were applied February 22, 2011, and February 7, 2012, respectively. Treatments were applied in a spray volume of 280 L·ha⁻¹ (30 gal·A⁻¹) using a hand-held sprayer with four TeeJet 8002VS nozzles (Spraying Systems Co., Wheaton, IL) spaced at 25 cm (9.8 in). Adequate irrigation was applied 24 hours after treatment application. Treatments were applied to 1.5 by 3 m (5 by 9.8 ft) plots arranged in a randomized complete block design with 3 replications. Data were collected 14, 28, and 42 days after initial treatment (DAIT). Seedheads within a 0.093 m² (1 ft²) frame were counted and data were then expressed as seedhead suppression in comparison to the nontreated. Turfgrass (perennial ryegrass) injury was rated visually on a 0 to 100 scale where 0 equals no injury and 100 equals complete plant death. Injury equal to or greater than 20% was considered commercially unacceptable. Data were analyzed in SAS using PROC GLM. Means were separated using an LSD with α = 0.05 for use as a general comparison.

Results and Discussion

Pre-seeding cultural practices. Interactions between overseeding rate by date by location, and overseeding rate by cultural practice were found, and therefore, data are presented.
separately. Turfgrass quality (TQ) was mostly influenced by perennial ryegrass overseeding rate ($F = 523.87$) rather than location ($F = 164.83$), rating date ($F = 107.33$), and pre-seeding cultural method ($F = 10.07$). In general, lowest TQ ratings were noticed at seeding, due to turfgrass disruption caused by pre-seeding cultural methods. After overseeding establishment, TQ generally increased as overseeding rate increased, due to the amount of green, actively growing turfgrass. Overall, cultivation methods did not improved TQ of overseeded plots (Table 1), compared to non-overseeded ones. Solid tine aeration resulted in reduced TQ of plots overseeded with 500 kg·ha$^{-1}$ (445 lb·A$^{-1}$) in Pisa. Also in Pisa, cultivation methods including scalping resulted in superior TQ scores (7.5 and 7.8 for scalping and scalping plus vertical mowing, respectively) compared to non-overseeded plots (6.5). No differences were observed in Auburn for any cultivation method for each overseeding rate.

Most pronounced differences between non-overseeded and overseeded plots were observed on January 2, 2012 (Table 2). At this date, bermudagrass discoloration resulting from dormancy greatly reduced TQ scores for non-overseeded plots (3.3 and 1.0, for Auburn and Pisa, respectively). Overseeding with perennial ryegrass in Auburn resulted in TQ scores equal to or greater than 7.5, independently of the rate. In Pisa, overseeding at 500 kg·ha$^{-1}$ (445 lb·A$^{-1}$) resulted in TQ of 5.8, whereas the rate of 1,000 kg·ha$^{-1}$ (890 lb·A$^{-1}$) resulted in a 6.9 TQ score. In Pisa, highest TQ scores for overseeded plots were achieved in May 15, 2012 (7.3 and 7.1, for 500 and 1,000 kg pure live seed·ha$^{-1}$, respectively); whereas in Auburn no differences for overseeded and non-overseeded plots were observed in May. Bermudagrass spring green up in May likely reduced the effect of perennial ryegrass overseeding on TQ in both locations, especially in Auburn.

According to our results, cultural practices did not consistently enhance perennial ryegrass overseeding establishment in bermudagrass turf (White and Dickens 1984, Cox et al. 2013). Conversely, other studies found vertical mowing, scalping, and aerification enhanced overseeding establishment (Schmidt et al. 1970, Schmidt and Shoulders 1977). Schmidt and Shoulders (1977), however, performed aerification throughout the summer as a mean to reduce thatch accumulation, whereas in our study, solid-tine aerification was performed immediately 1 week prior to overseeding, and this did not enhance overseeding establishment. Despite the controversy, scalping may enhance TQ of overseeded plots, as observed in our research in Pisa.

### Table 1. Turfgrass quality (TQ) and rating dates for bermudagrass overseeded with 500 and 1000 kg perennial ryegrass·ha$^{-1}$ in Auburn, AL, and Pisa, Italy, in 2011–12.

| Overseeding rate (kg pure live seed·ha$^{-1}$) | Auburn | Pisa | Auburn | Pisa | Auburn | Pisa |
|---|---|---|---|---|---|---|
| 0 | Sep 21 2011 | 4.3 | 6.3 | 4.4 | 3.5 | 1.0 | 5.3 |
| 500 | 4.3 | 6.1 | 7.5 | 6.5 | 4.4 | 5.7 | 5.8 | 7.3 |
| 1000 | 4.3 | 6.8 | 7.8 | 7.1 | 4.4 | 6.7 | 6.9 | 7.1 |

*LSD (0.05)*

### Table 2. Effect of perennial ryegrass seeding rate and cultural practices on turfgrass quality (TQ) in 2 January 2012 in Auburn, AL, and Pisa, Italy.

| Cultural method | Auburn | Pisa | Auburn | Pisa | Auburn | Pisa |
|---|---|---|---|---|---|---|
| None | 3.3 | 1.0 | 7.8 | 5.3 | 8.3 | 6.5 |
| Scanning | 3.5 | 1.0 | 7.8 | 6.9 | 8.3 | 7.5 |
| Solid tine aerification | 3.5 | 1.0 | 6.8 | 4.4 | 7.0 | 6.4 |
| Vertical mowing | 3.0 | 1.0 | 7.5 | 5.5 | 7.5 | 6.6 |
| Vertical mowing + scalping | 3.3 | 1.0 | 7.8 | 7.0 | 8.5 | 7.8 |

*LSD (0.05)*

*Overseeding rates were 0, 500, and 1000 kg pure live seed·ha$^{-1}$. Overseeding date was September 20, 2011, in Auburn, AL, and Pisa, Italy.*

*Turfgrass quality measured on a 1–9 scale (1 = brown/dead turf, 6 = minimal acceptable turf, 9 = ideal green, healthy turf). TQ was evaluated based on overall plot aesthetics, including turfgrass color, density, and health.*

*Least significant difference according to Fisher’s protected test at $\alpha = 0.05$.***
During spring transition, there was an interaction between overseeding species and seeding rate on plant density, as well as location and rating date. For this reason, cover ratings are presented for each individual location and overseeding rate (Table 3). Overall, overseeding with perennial ryegrass reduced spring bermudagrass cover, as noticed in Auburn. Bermudagrass density increased in non-overseeded plots from April to June 2012, whereas in overseeded plots, it was reduced from April to June 2012. On May 16, 2012, bermudagrass cover in Auburn was also affected by overseeding rates: 61 and 54% for 500 and 1,000 kg·ha⁻¹ (445 and 890 lb·A⁻¹), respectively. In agreement with our findings, a decrease in bermudagrass cover due to increasing overseeding rates has been reported by Kopec et al. (2001) as a likely result of interspecific competition between perennial ryegrass and bermudagrass during the fall, winter, and spring transition (Chalmers 1986). Overall, perennial ryegrass density decreased from April through June 2012. In Auburn, plots overseeded with perennial ryegrass at 1,000 kg·ha⁻¹ (890 lb·A⁻¹) had greater perennial ryegrass density on May 16, 2012 (38%) and July 15, 2012 (32%), compared to plots overseeded with 500 kg·ha⁻¹ (445 lb·A⁻¹) (28 and 23% for May and June, respectively). Overseeding rate did not affect perennial ryegrass density in Pisa. Furthermore, persistency of perennial ryegrass in our study through June 2012 may justify chemical removal of the overseeded species, considering that complete spring transition of perennial ryegrass is not achieved using cultural practices (Horgan and Yelverton 2001, Summerford et al. 2009). For this reason, it is important to consider an appropriate overseeding rate to maintain green color through the winter, and yet result in a vigorous bermudagrass spring transition.

Annual bluegrass was suppressed by overseeding with perennial ryegrass, regardless of the rate, in both locations. In Auburn, though, annual bluegrass density of non-overseeded plots decreased similar to overseeded plots by May 16, 2012. Annual bluegrass infestation in Pisa persisted on non-overseeded plots through June 2012.

### Table 3. Effect of perennial ryegrass overseeding rates and date on species density for bermudagrass, perennial ryegrass, and annual bluegrass in Auburn and Pisa in 2012.

| Overseeding rate | Date       | Bermudagrass | Perennial ryegrass | Annual bluegrass | Bermudagrass | Perennial ryegrass | Annual bluegrass |
|------------------|------------|--------------|--------------------|------------------|--------------|--------------------|------------------|
| 0                | April 2, 2012 | 50           | 0                  | 50               | 100          | 0                  | 16               |
|                  | May 16, 2012 | 91           | 0                  | 1                | 100          | 0                  | 18               |
|                  | June 15, 2012| 82           | 1                  | 0                | 100          | 0                  | 19               |
| LSD (0.05)       |            | 5.9          |                    | 3.8              |              |                    |                  |
| 500              | April 2, 2012 | 70           | 29                 | 1                | 16           | 83                 | 2                |
|                  | May 16, 2012 | 61           | 28                 | 1                | 54           | 44                 | 2                |
|                  | June 15, 2012| 58           | 23                 | 0                | 64           | 34                 | 2                |
| LSD (0.05)       |            | 8.2          |                    | 5.7              |              |                    |                  |
| 1000             | April 2, 2012 | 66           | 30                 | 5                | 16           | 82                 | 1                |
|                  | May 16, 2012 | 54           | 38                 | 0                | 55           | 44                 | 1                |
|                  | June 15, 2012| 49           | 32                 | 0                | 63           | 35                 | 1                |
| LSD (0.05)       |            | 6.7          |                    | 4.8              |              |                    |                  |

Overseeding was done at 500 and 1000 kg pure live seed·ha⁻¹ on September 20, 2011. Auburn used ‘Top Gun II’ perennial ryegrass (Jacklin Seed by Symplot, Post Falls, ID). Pisa used ‘Gray Fox’, ‘Inspire’, and ‘Silver Dollar’ perennial ryegrass (Everris Italia, Treviso) blend, on a 25-25-50 percent basis.

Density measured with a 1 by 1 m grid containing 25 intersections. The species that fell directly under an intersection were counted. Count data were converted to percentage.

Least significant difference according to Fisher’s protected test at α = 0.05.

### Table 4. Effect of overseeding rates in annual bluegrass suppression 175 DAS in Auburn, AL, and Riverside, CA.

| Overseeded species | Seeding rate | Bermudagrass | Annual Bluegrass | Overseeded species |
|--------------------|--------------|--------------|------------------|--------------------|
| Nontreated         | —            | 50           | 50               | 0                  |
| Perennial ryegrass | 111          | 34           | 17               | 49                 |
|                    | 222          | 32           | 14               | 53                 |
|                    | 444          | 22           | 8                | 71                 |
|                    | 888          | 22           | 4                | 74                 |
| Rough bluegrass    | 55           | 43           | 13               | 44                 |
|                    | 111          | 26           | 8                | 66                 |
|                    | 222          | 20           | 7                | 74                 |
| LSD (0.05)         | 8.8          | 7.2          | 10.7             |                    |

Kg pure live seed·ha⁻¹.

March 27, 2011, for Auburn, and April 7, 2011, for Riverside.

Data pulled across Auburn and Riverside locations (P = 0.052).

Least significant difference according to Fisher’s protected test at α = 0.05.
Overseeding rate. Count data were combined across both locations and years as no significant interactions were seen ($F = 0.052$). Also, a year by treatment interaction was not detected for Auburn ($F = 0.0516$), therefore data were combined across years for subsequent analysis. Green cover data is presented individually for overseeded species and location. In general, both overseeded species reduced annual bluegrass population, though complete suppression was not achieved (Table 4). Compared to non-overseeded plots, perennial ryegrass resulted in annual bluegrass increasing reduction from 50% on the non-overseeded to 4% when overseeded at 888 kg·ha$^{-1}$ (1,000 lb·A$^{-1}$) 175 DAS. Also at 175 DAS, overseeded roughstalk bluegrass resulted in annual bluegrass density reduction of 37 to 43% compared to the non-overseeded, independently of the rate. Elford et al. (2008) concluded that increasing seeding rates and frequency of perennial ryegrass resulted in increased weed suppression. Kentucky bluegrass and tall fescue have also been reported to suppress weed density at higher seeding rates (Beard et al. 1980; Busey 1989). Our results are in agreement with previous literature. The lack of significant differences in annual bluegrass reduction for higher overseeding rates of and all tested rates of roughstalk bluegrass, however, suggest the existence of a threshold for overseeding rate increase for annual bluegrass suppression. Density of the overseeded species followed the same trend as for perennial ryegrass, with a 49 to 53% increase for overseeding rates up to 222 kg·ha$^{-1}$ (200 lb·A$^{-1}$), and a 71 to 74% increase in density for rates equal or greater than 444 kg·ha$^{-1}$ (400 lb·A$^{-1}$). For roughstalk bluegrass, whereas annual bluegrass occurred independently of the seeding rate, increase in roughstalk bluegrass density was rate-dependent: 44% for 55 kg·ha$^{-1}$ (50 lb·A$^{-1}$), and 66 to 74% for rates equal or greater than 111 kg·ha$^{-1}$ (100 lb·A$^{-1}$).

In regard to green cover, most noticeable increase in turfgrass green cover (TGC) was seen 100 DAS (January) for both overseeded species (Fig 1A, 1B, 2A, 2B). In Auburn, perennial ryegrass overseeded at 444 and 888 kg pure live
Table 5. Effect of plant growth regulators applied to bermudagrass overseeded with perennial ryegrass on annual bluegrass seedhead suppression and perennial ryegrass injury*, in Auburn AL, in 2011 and 2012.

| Treatment*          | Rate (kg ai·ha⁻¹) | 2011  | 2012  | Injury in 2012 by DAT (%) |
|---------------------|------------------|-------|-------|--------------------------|
|                     |                  | 14    | 28    | 42           | 14 | 28 | 42 |
| mefluidide          | 0.56             | 70    | 73    | 92          | 53 | 100| 100| 0  | 33 | 57 |
| paclobutrazol       | 0.28             | 87    | 70    | 85          | 60 | 97 | 100| 0  | 5  | 0  |
| flurprimidol        | 0.42             | 83    | 67    | 83          | 63 | 82 | 90 | 0  | 0  | 0  |
| trinexapac-ethyl    | 0.38             | 95    | 63    | 78          | 53 | 95 | 100| 0  | 0  | 0  |
| trinexapac-ethyl + ethephon | 0.01 + 3.82 | 83    | 80    | 85          | 0  | 58 | 65 | 0  | 0  | 0  |
| LSD (0.05)          | 16.1             | 20.2  | 12.6  |             | 19.7| 15.6| 15.5| 0  | 5.3| 4.9|

*Seedhead suppression assessed visually, on a percent basis relative to the nontreated, where 0 represents seedhead production similar to nontreated and 100 represents no seedhead production.

1Injury was assessed visually, on a percent basis relative to the nontreated. Injury exceeding 20% was considered commercially unacceptable. No injury was observed in 2011, therefore, data presented refer to 2012 only.

2All treatments reapplied 28 days after initial application at the same rates. Initial treatments were applied February 22, 2011, and February 7, 2012.

3Days after initial application.

4Least significant difference according to Fisher’s protected test at α = 0.05.

seed·ha⁻¹ (400 and 800 lb·A⁻¹) resulted in similar TGC (P < 0.0001) (Fig 1A), which is in agreement with Elford et al. (2008), when TGC and overseeding rates were correlated in a quadratic fashion. Differently, increasing perennial ryegrass overseeding rates in Riverside resulted in a steady increase in percent green cover (Fig 2A). For roughstalk bluegrass, most increase in green cover from overseeded roughstalk bluegrass also occurred 100 DAS in both locations, and resulted from 111 kg pure live seed·ha⁻¹ (P = 0.0002) (Fig 2B). Little contribution from both overseeded species was noticed beyond 100 DAS (Fig 1A, 1B, 2A, 2B), likely due to bermudagrass spring green up. Tillering of the cool-season species associated with greening up of the bermudagrass could explain greater TGC 130 and 175 DAS. Whereas increasing roughstalk bluegrass and perennial ryegrass overseeding rates can improve green cover when bermudagrass is dormant, little to no contribution in TGC from overseeding was noticed in our study during bermudagrass spring green up. Based on these results, desirable turfgrass green cover and annual bluegrass suppression can be achieved via overseeding with perennial ryegrass and roughstalk bluegrass. Remaining annual bluegrass could be chemically treated for seedheads suppression, aiding in improving aesthetic quality, as discussed below.

PGR seedhead suppression. The two experiments (2010–11 and 2011–12 seasons) were separated due to a treatment by year interaction. Paclobutrazol, flurprimidol, and trinexapac-ethyl effectively suppressed annual bluegrass seedheads without injuring perennial ryegrass (Table 5). In 2011 and 2012, respectively, paclobutrazol applied at 0.28 kg ha⁻¹ (0.25 lb·A⁻¹) suppressed annual bluegrass seedheads by 85 and 100% compared to the nontreated control 42 DAIT. Flurprimidol at 0.42 kg ha⁻¹ (0.27 lb·A⁻¹) and trinexapac-ethyl at 0.382 kg ha⁻¹ (0.34 lb·A⁻¹) resulted in 83 to 90%, and 78 to 100% seedhead suppression, respectively, at the same timing. Paclobutrazol and flurprimidol have been reported to be injurious to creeping bentgrass (Johnson and Murphy 1995), but safe to perennial ryegrass and roughstalk bluegrass according to our results. Fagerness and Penner (1998) reported trinexapac-ethyl only suppressed annual bluegrass seedheads 43 to 57% compared to the nontreated, and Eggens and Wright (1985) reported ethephon only reduced annual bluegrass shoot dry weight when applied above 2 kg·ha⁻¹ (1.8 lb·A⁻¹). Although trinexapac-ethyl (0.0095 kg·ha⁻¹, 0.008 lb·A⁻¹) plus ethephon (3.82 kg·ha⁻¹, 3.4 lb·A⁻¹) suppressed annual bluegrass seedheads 28 DAIT in 2011, it was the least effective treatment in 2012. Trinexapac-ethyl plus ethephon yielded the same annual bluegrass seedhead suppression as paclobutrazol 42 DAIT. Nonetheless, mixtures of ethephon and trinexapac-ethyl should be further investigated based upon its potential for annual bluegrass seedhead suppression as shown in Table 5 (28 DAIT in 2011), as well as by previous research (Bigelow and Hardebeck 2004). No turfgrass injury was observed from any treatment except mefluidide. Mefluidide caused unacceptable injury (>30%) to perennial ryegrass in 2012 (Table 5). Injury from mefluidide has been previously reported by Neff et al. (1999), who reported annual bluegrass seedhead suppression was greater for mefluidide than paclobutrazol. Chemical applications by Neff et al. (1999), however, were made in January, while our applications were made in February and March.

Research implications. Pre-seeding cultural methods prior to overseeding yielded little to no contribution to establishment of the overseeding species in this study. Only methods involving scalping resulted in improved TQ, as demonstrated in Pisa. Overseeding generally resulted in improved TQ relative to non-overseeded treatments, providing improved green cover while the bermudagrass is dormant. Increased turfgrass green cover and annual bluegrass suppression could be achieved with increasing overseeding rates of perennial ryegrass and roughstalk bluegrass, though it may impact bermudagrass spring transition as observed by reduced bermudagrass density. Most improvement from overseeding in turfgrass green cover occurred 100 DAS (in January), though greater green cover was observed 130 and 175 DAS, with post-dormant bermudagrass. Paclobutrazol, flurprimidol, and trinexapac-ethyl can be used effectively to improve turf aesthetics by effectively reducing remaining
annual bluegrass seedheads safely to the overseeded species. Overall, these studies suggest that annual bluegrass can be effectively managed in overseeded bermudagrass through the appropriate combination of overseeding rate and seedhead suppression treatment.

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