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# Overseeding cool-season annual grasses into dormant lowland switchgrass stands

**Pattarawan Watcharaanantapong**[1] | **Patrick D. Keyser**[2] | **David W. McIntosh**[1] | **Andrew P. Griffith**[1]

[1] Univ. of Tennessee, Knoxville, TN 37996, USA

[2] Center for Native Grasslands Management, Univ. of Tennessee, 2431 Joe Johnson Dr., Knoxville, TN 37996, USA

**Correspondence**
Patrick D. Keyser, Center for Native Grasslands Management, Univ. of Tennessee, 2431 Joe Johnson Dr., Knoxville, TN 37996, USA.
Email: pkeyser@utk.edu

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**Abstract**

Improved use of the land resource used to grow switchgrass (SG; *Panicum virgatum* L.), whether for biomass or forage production, could be achieved by dormant-season overseeding with cool-season annual grasses (CAGs). Cereal rye (*Secale cereale* L.), ryegrass (*Lolium multiflorum* Lam.), and wheat (*Triticum aestivum* L.) were overseeded into an established, mature stand of lowland ('Alamo') SG for two consecutive years (2010–2011) at a study site located near Greeneville, TN. Three harvest timings were imposed on CAG (15 April, 1 May, and 15 May). Yield of CAG differed ($p = 0.001$) by year, species (rye = 6.8, ryegrass = 5.0, wheat = 5.1 Mg ha$^{-1}$), and harvest time (15 April = 2.7, 1 May = 6.5, 15 May = 7.7 Mg ha$^{-1}$), but these factors did not interact. Switchgrass yield the summer following establishment of CAGs differed ($p = .001$) by year (11.1 and 14.7 Mg ha$^{-1}$, in 2011 and 2012, respectively) but not by CAG species or harvest date. Tiller density of SG followed the same pattern as yield (2011 = 75 m$^{-2}$; 2012 = 147 m$^{-2}$). Thus, this study provided no evidence that any of the three CAGs, when planted for two consecutive years into dormant SG, regardless of harvest date, had a negative effect on SG yield or stand vigor; therefore, overseeding CAGs may be a practical way for producers to improve land resource use when growing SG. However, evaluation of production costs for CAGs indicated that May harvests would be required for overseeding to be cost-effective.

## 1 | INTRODUCTION

Increased use of switchgrass (SG), a warm-season perennial grass, as a biomass crop has the potential to displace forage production (Backus et al., 2017; Lowe et al., 2016; McIntosh et al., 2016). Furthermore, SG, regardless of the production model (forage, biomass, or both), does not produce biomass or forage during its dormant period (November–March), leaving an underutilized land resource. One prospective strategy to offset lost forage production and to more fully utilize the land resource is to overseed dormant SG stands with cool-season annual grasses (CAGs) (Butler, Muir, Huo, & Guretzky, 2013). Several studies have emphasized the potential of SG to extend grazing seasons by complementing CAG pastures (Biermacher, Haque, Mosali, & Rogers, 2017; Mosali, Biermacher, Cook, & Blanton, 2013; Vogel, 2004).

Cereal rye (*Secale cereale* L.), ryegrass (*Lolium multiflorum* Lam.), and wheat (*Triticum aestivum* L.) are CAGs that have been widely used to provide livestock forage (Ball, Hoveland, & Lacefield, 2015; Clark, 2007; McCartney, Fraser, & Ohama, 2008; Mullenix & Rouquette,

**Abbreviations:** CAG, cool-season annual grass; SG, switchgrass

2018). These CAGs have commonly been overseeded into other perennial warm-season grasses [i.e., bermudagrass [*Cynodon dactylon* (L.) Pers.] and bahiagrass (*Paspalum notatum* Flüggé)] to extend grazing seasons (Beck, Stewart, Phillips, Watkins, & Gunter, 2007; McLaughlin, Sistani, Fairbrother, & Rowe, 2005; Mullenix & Rouquette, 2018; Wyatt, Venuto, Gillespie, Blouin, & Redfearn, 2012). Furthermore, CAGs can have other benefits, including weed suppression, improved soil structure, and nutrient cycling (Clark, 2007). Where SG is grown as a biomass crop, use of an integrated crop–livestock system where CAGs are grazed could provide winter forage supply as well as additional benefits, such as increased organic matter, weed suppression, improved nutrient cycling, and reduced overall feed expenditures (Sulc & Tracy, 2007).

The planting and harvest management of overseeded CAGs could potentially affect the yield and vigor of warm-season perennial swards. Research by Fribourg & Overton (1973) focused on bermudagrass, another warm-season perennial grass, also indicated reduced yields resulting from overseeding CAGs and the timing of their harvest. They reported that ryegrass had the greatest impact on bermudagrass yields and that later harvests reduced the yields of bermudagrass more than early harvests. Similarly, Welch, Wilkinson, and Hillsman (1967) reported that reductions in bermudagrass yield were a function of fertility inputs for overseeded rye resulting in greater stand density of the CAGs and more competition for the perennial warm-season grass. Working in a semi-arid environment, White, Muir, and Lambert (2018) reported that, in addition to spring competition to the bermudagrass from the cool-season annuals, winter and spring moisture availability also depressed yields for the warm-season grass.

With respect to native warm-season grasses, there has been much less research. Studies examining overseeding cool-season legumes into native warm-season grasses have reported reduced canopy cover (Keyser et al., 2016) and yield of SG (George, Blanchet, Gettle, Buxton, & Moore, 1995). On the other hand, Mason et al. (2019) did not detect any reductions in eastern gamagrass (*Tripsacum dactyloides* L.) production as a result of overseeding CAGs. Butler et al. (2013) reported reduced yields for Alamo SG overseeded with rye despite an early April harvest date. At a second location, they did not observe an effect on SG yield as a result of rye overseeding (Butler et al., 2013).

Additional research is needed to help determine the feasibility of a system where winter annuals can be overseeded into dormant switchgrass. Such an approach could increase overall yield per hectare (Foulia et al., 2012) and offset lost forage production associated with biomass production (Backus et al., 2017). Therefore, an experiment was implemented to determine the productivity and economic feasibility of establishing three CAGs (rye, ryegrass, and wheat) into dormant SG and the influence of harvest timing (15 April, 1 May, and 15 May) of these CAGs on SG yield and stand vigor. We hypothesized that SG yield and stand vigor as measured by tiller density would be negatively affected by overseeding of CAGs. Furthermore, we hypothesized that later-maturing CAGs (i.e., wheat and ryegrass) and later harvest dates, especially those on 15 May, would have a disproportionately negative impact on these factors.

**Core Ideas**

- Improved land resource use is needed when growing switchgrass biomass or forage.
- Overseeded cool-season annual grasses may achieve improved land resource use.
- Overseeded cereal rye, ryegrass, and wheat produced acceptable yields.
- Switchgrass yield was not affected by cool-season annual species or harvest date.
- Switchgrass stand vigor was not affected by two consecutive years of overseeding.

## 2 | MATERIALS AND METHODS

### 2.1 | Location

The experiment was conducted from October 2010 to December 2012 at the Research and Education Center at Greeneville, TN (36.06° N, 82.84° W; 540 m asl). The soil classification of the planting area was a Dunmore silty clay loam (fine, kaolinitic, mesic Typic Paleudult) (Soil Survey Staff, 2019).

### 2.2 | Species and design

The experiment was a randomized block design with two factors (overseeded CAG species and harvest timing of CAGs, arranged factorially) with four replicates. Three cultivars of CAG—Winter Magic (cereal rye), Marshall (ryegrass), and Forage Max (wheat) —were overseeded into an existing stand of SG ('Alamo'). In addition, we included a control where no CAG was planted. The second factor in this experiment was harvest time of the CAGs. Each CAG was exposed to a single spring harvest at one of three dates: 15 April (early), 1 May (middle), or 15 May (late). All treatment levels had a single, post-dormancy biomass harvest.

The study was repeated for a second year with CAGs and harvest treatments applied to the same plot in both years to evaluate potential cumulative impact of the CAGs on SG sward vigor. To increase sample size, we installed a second identical experiment at the same location and on a site with the same soil types. Although it may have been preferable to add a second location with greater variability in environmental and soil conditions, that was not an option at the time the study was implemented. For the second experimental location, we repeated the treatments on the same plots in both experimental years as was done for the first experimental location.

## 2.3 | Establishment

Switchgrass had been established in May 2008 at the rate of 6.7 pure live seed kg ha$^{-1}$ and had not been harvested prior to the initiation of this study in 2010. Annual growth was removed by burning in March 2008 and again in March 2009. In October 2010 and 2011, the SG was mowed to a 15-cm residual height, and residue was removed from the field. The CAGs were planted in 2.1 m by 6.1 m experimental plots using a no-till drill (Model NT 606, Great Plains Manufacturing, Inc.) in late October 2010 and again in 2011. Seeding rates for the CAGs were 107 kg ha$^{-1}$ for cereal rye and wheat and 13.6 kg ha$^{-1}$ for ryegrass.

## 2.4 | Fertilization

All plots received 22 kg N ha$^{-1}$ annually at establishment of CAGs. Need for P, K, and lime was assessed annually by soil test per recommendations of the Soil, Plant and Pest Center at the University of Tennessee Institute of Agriculture. No supplemental P, K, or lime was added during the course of the experiments. In early March each year, all plots were topdressed with 67 kg N ha$^{-1}$. All plots received an additional 67 kg N ha$^{-1}$ after the final CAG harvest (15 May) each year. All N applied was in the form of urea (46–0–0).

## 2.5 | Data collection

Harvests for the CAGs were conducted annually (2011 and 2012) using a flail-type harvester (Carter Manufacturing Company, Inc.) at 15-cm residual height. Based on the width of the cutting head on the harvester, the center 0.91 m (along the long axis) of each plot was harvested for yield for CAGs on the designated dates. Switchgrass was harvested from the plot center (0.91 m width) to a 15-cm residual height in early November each year (2011 and 2012). All harvested samples of CAG and SG were weighed to determine yield with a grab sample retained and oven dried at 55 °C for at least 72 h in a forced-air oven to determine moisture content. In October 2010, prior to CAG planting, we counted all SG tillers within two randomly placed 0.25-m$^2$ subsamples per experimental unit. Counted SG tillers were multiplied by 4 to calculate total per square meter. A final SG tiller count was conducted in November 2012 following the final harvest using the same approach.

## 2.6 | Climatological data

Precipitation and temperature data were collected on site and retrieved from the National Weather Service Forecast Office (National Oceanic and Atmospheric Administration [NOAA]) in Morristown, TN. The 30-yr monthly mean temperature and rainfall data were also obtained from NOAA (NOAA, 2019). The winter of 2010–2011 was unusually cold, with temperatures in December and January well below 30-yr means (Figure 1). However, during the spring growth period for CAGs (February–May), temperatures remained at or above 30-yr means (Figure 1). Likewise, temperatures during the active growth period of SG (May–September) were at or above the 30-yr means (Figure 1). Precipitation following establishment of CAGs in 2010 was limited (November–January) but was above the 30-yr mean during those months for the 2011 plantings of CAGs (Figure 2). During the spring growth period for CAGs except February, precipitation remained at or above the 30-yr mean in both years (Figure 2). During the growth period for SG, precipitation was above the 30-yr mean except for June 2012, during which there was no measured precipitation (Figure 2).

## 2.7 | Statistical methods

All data were analyzed using a mixed-effect ANOVA model (PROC GLIMMIX) in SAS 9.4 (SAS Institute, 2013). Yield of CAGs, yield of SG, and SG tiller density were dependent variables and were analyzed with species (cereal rye, ryegrass, and wheat), harvest time, year, and the interaction of these factors as fixed effects, with replicates as a random effect. We used a repeated-measures (covariate structure, "unstructured" in SAS) analytical approach because we sampled the same plots in all years and thus anticipated temporal dependence. We treated the two identical experiments (i.e., "location") as the blocking factor. Mean separations ($p < .05$) were conducted using Fisher's protected LSD. There were no severe outliers and assumptions regarding normality ($p = .022$), and equality of variances based on the Levene test were met.

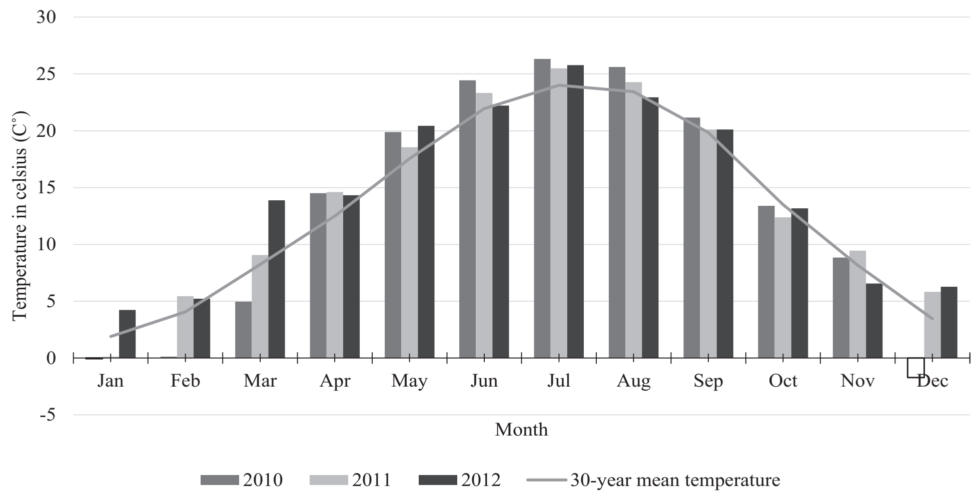


**FIGURE 1** Monthly mean temperature (2010–2012) with 30-yr mean temperature for Research and Education Center at Greeneville, TN, NOAA Morristown Weather Forecast Office (NOAA, 2019)

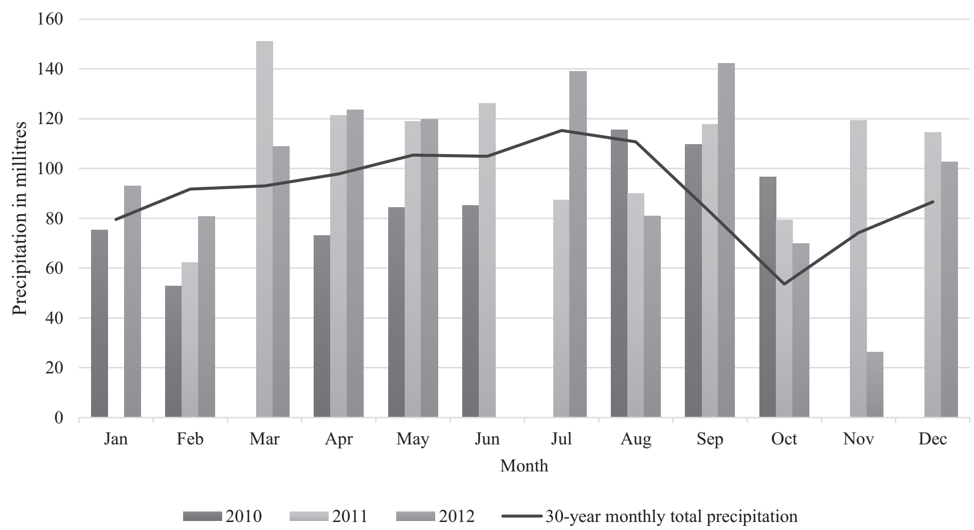


**FIGURE 2** Monthly total precipitation (2010–2012) with 30-yr mean precipitation for Research and Education Center at Greeneville, TN, NOAA Morristown Weather Forecast Office (NOAA, 2019)

## 2.8 | Economics

Establishing productivity of CAGs within dormant SG is important, but an understanding of the cost of such production is also informative for producers making management decisions. Therefore, we evaluated cost of production for the CAGs based on the yields they produced in our experiment. Although we did not conduct grazing as a part of this study, producers may choose to use CAGs through grazing rather than hay harvest. Therefore, we include an evaluation of the cost of removal of CAGs through grazing in addition to that for hay harvest. Enterprise budgeting was used to estimate production costs for each CAG treatment for both grazing and haying (Tables 1 and 2). Average custom rates were used for field operations including no-till seeding, fertilizer application, mowing, baling, and hauling (Bowling, 2013). Baling and hauling were assumed to be a function of CAG yield, whereas the other field operations were priced on an area (hectare) basis. Establishment costs for CAGs included seed, fertilizer, and land rent. No additional expenses were incorporated for grazing. An operating expense of 5% for 6 mo was also included in the estimated cost.

Production cost estimates for grazing and haying each treatment were analyzed using PROC MIXED in SAS 9.4 (SAS Institute), with year and replication as random effects

**TABLE 1** Estimated establishment expenses for cool-season annual grasses overseeded into dormant switchgrass

| Item | Price |
|---|---|
| | $ ha$^{-1}$ |
| Seed | |
| Rye | 89.64 |
| Wheat | 63.69 |
| Ryegrass | 35.98 |
| No-till grass drill | 34.59 |
| Fertilizer (N) | 85.31 |
| Fertilizer application | 39.54 |
| Land rent | 51.89 |

**TABLE 2** Estimated expenses for mechanical harvest of cool-season annual grasses overseeded into dormant switchgrass

| Item | Unit | Price |
|---|---|---|
| | | $ ha$^{-1}$ |
| Mowing/swathing | ha | 37.07 |
| Baling | bale[a] | 13.00 |
| Hauling/staging | bale[a] | 4.50 |

[a] Bale is assumed to be 0.544 Mg; expense is per bale rather than per ha.

and treatment as the fixed effect. Cost estimate means were compared using SAS least square means with the Tukey adjustment at $P \leq .05$.

## 3 | RESULTS

Yield for CAGs differed ($p < .001$) for year, species, and harvest time, but there was no interaction among these factors (Table 3). Yields for all CAG species in 2012 were greater than those in 2011 (Table 4). Within CAG species, mean yield from rye exceeded that of ryegrass and wheat, which did not differ from each other (Table 4). Yield of CAGs increased with progression in harvest date (Table 4). With the exception of year ($p < .001$), neither species (including unplanted controls) nor harvest time nor interaction among these factors affected SG yield (Table 5). Yield of SG in 2012 (14.7 ± 0.91 Mg ha$^{-1}$) exceeded that of 2011 (11.1 ± 0.92 Mg ha$^{-1}$) (Table 5). Likewise, SG tiller density varied by year but was not affected by any other factors or their interaction (Table 6). Mean SG tiller density was 74.2 ± 6.59 m$^{-2}$ in 2010 and 146.1 ± 6.59 m$^{-2}$ in 2012. These results were all contrary to our hypotheses regarding SG yield and

**TABLE 3** Results of mixed ANOVA for cool-season annual grass yield in switchgrass overseeding experiment at Research and Education Center at Greeneville, TN, 2011–2012

| Effect | df | *F*-value | *P*-value |
|---|---|---|---|
| Year | 1 | 151.39 | <.001 |
| Species | 2 | 32.41 | <.001 |
| Harvest time | 2 | 200.76 | <.001 |
| Species × year | 2 | 0.29 | .749 |
| Species × harvest time | 4 | 0.25 | .909 |
| Year × harvest time | 2 | 0.39 | .678 |
| Species × year × harvest time | 4 | 0.47 | .760 |

**TABLE 4** Means (SEM = 1.324) for cool-season annual grass yield by year, species, and harvest time in overseeding experiment at Research and Education Center at Greeneville, TN, 2011–2012

| Treatment | | Yield |
|---|---|---|
| | | Mg ha$^{-1}$ |
| Year | 2011 | 4.33B[a] |
| | 2012 | 6.96A |
| Species | Rye | 6.84A |
| | Ryegrass | 4.99B |
| | Wheat | 5.09B |
| Harvest time | 15 Apr. | 2.72C |
| | 1 May | 6.53B |
| | 15 May | 7.67A |

[a] Means within each treatment and without common letters significantly differ ($p < .05$).

**TABLE 5** Results of mixed ANOVA for switchgrass yield in cool-season annual grass overseeding experiment at Research and Education Center at Greeneville, TN, 2011–2012

| Effect | df | *F*-value | *P*-value |
|---|---|---|---|
| Year | 1 | 36.38 | <.001 |
| Species | 3 | 3.55 | .164 |
| Harvest time | 2 | 0.81 | .456 |
| Species × year | 3 | 0.51 | .682 |
| Species × harvest time | 6 | 1.04 | .424 |
| Year × harvest time | 2 | 0.09 | .914 |
| Species × year × harvest time | 6 | 0.18 | .980 |

**TABLE 6** Results of mixed ANOVA for switchgrass tiller density in cool-season annual grass overseeding experiment at Research and Education Center at Greeneville, TN, 2011–2012

| Effect | df | *F*-value | *P*-value |
|---|---|---|---|
| Year | 1 | 59.54 | <.001 |
| Species | 3 | 1.10 | .353 |
| Harvest time | 2 | 0.41 | .668 |
| Species × year | 3 | 0.52 | .668 |
| Species × harvest time | 6 | 0.54 | .778 |
| Year × harvest time | 2 | 0.74 | .4816 |
| Species × year × harvest time | 6 | 0.70 | .6480 |

**TABLE 7** Estimated cost of producing cool-season annual grasses overseeded into dormant switchgrass

| Treatment[a] | Cost grazing[b] | Cost mechanically harvested |
|---|---|---|
| | $ Mg$^{-1}$ | |
| Rye late | 35.60A | 73.94A |
| Ryegrass late | 37.45A | 77.09A |
| Rye mid | 40.64A | 79.74A |
| Wheat late | 41.73A | 81.49A |
| Ryegrass mid | 48.04A | 89.57A |
| Wheat mid | 49.31A | 90.31A |
| Rye early | 93.62A | 140.74A |
| Ryegrass early | 249.49B | 327.01B |
| Wheat early | 274.61B | 352.36B |

[a] Early, 15 Apr. harvest; Late, 15 May harvest; Mid, 1 May harvest.
[b] Means within a column without letters significantly differ ($p < .05$).

tiller density in response to overseeded CAG species and harvest date for those CAGs.

The lowest-cost grazing and haying treatments analyzed in this study were CAG treatments that were harvested 15 May or 1 May (Table 7). Rye harvested on May 15 had the lowest expected cost at $35.60 Mg$^{-1}$ when grazing and $73.94 Mg$^{-1}$ when haying, whereas ryegrass harvested at the same time was $37.45 and $77.09 Mg$^{-1}$ for grazing and haying, respectively. The early harvest (15 April) of CAGs was cost prohibitive from a grazing and haying standpoint because the CAGs had relatively low forage production at that time.

## 4 DISCUSSION

Overseeding all three CAG species into existing SG produced acceptable yields from the annuals and could improve overall production from a given land area while extending grazing seasons. Yields of CAGs exceeded those of Fribourg and Overton (1973), who reported 2.1, 4.0, and 4.1 Mg ha$^{-1}$ for rye, ryegrass, and wheat, respectively, and Mason et al. (2019) (<1.1 Mg ha$^{-1}$) but were similar to those reported by Beck et al. (2007) and Butler et al. (2013) at their Oklahoma study site. Variability of CAG yields can be strongly affected by timing and amount of rainfall (McLaughlin et al., 2005; Mullenix & Rouquette, 2018), soil fertility (Butler et al., 2013), or density of the vegetation into which the annuals are being established (Fribourg & Overton, 1973; Mason et al., 2019; Mullenix & Rouquette, 2018). In our case, establishment success was good in both years for all three CAGs. Differences in CAG yield between 2011 and 2012 may have been a result of colder and drier conditions during CAG establishment and early stand development in the first year of our study.

Successful establishment of overseeded CAGs could help farmers extend the grazing period of SG and provide more net return to producers. For instance, Biermacher et al. (2017) indicated that producers could obtain a positive net return by extending the cereal forage grazing season by grazing SG and/or using the SG as a biomass crop, depending on relative market values of beef and biomass. The cost estimates of this study support Biermacher et al. (2017) for 1 May and 15 May harvests for grazed CAGs but not for CAGs fed as hay. However, other pasture forages may be available for grazing by May, which may mean the CAGs would not offset hay use. Furthermore, alternative forages available in May in the mid-South would most likely be perennials, such as tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.], and would therefore be more cost effective than annuals. Grazing CAGs earlier in the growing season (mid-February through mid-April) could offset hay feeding requirements during those months, but further research is required to validate economic trade-offs and outcomes.

As expected, later harvests of annuals produced greater yields without respect to species of CAG. The greater overall yield of rye was likely a result, in part, of the early maturity date of this forage relative to the others. Ryegrass is the latest to mature of these three CAGs, a fact that may explain the reduced yield for this species given the harvest dates, which all occurred prior to peak biomass accumulation of this species (Beck et al., 2007; Mullenix & Rouquette, 2018). Harvest timing of CAGs did not affect SG yield, indicating that CAG management could be flexible and that harvests could be timed for 1 May or later to avoid reduced CAG yield. Conversely, these results did not indicate a substantial advantage (only 1.1 kg ha$^{-1}$) would be realized by delaying CAG harvests until 15 May (Table 2). In the case of rye, advanced plant maturity at this later date may compromise forage quality. Had the CAGs been harvested through grazing, canopies would have been shorter, and, presumptively, competition with SG would have been reduced further.

## 5 CONCLUSIONS

There was no apparent cumulative impact on SG vigor from planting the CAGs for two consecutive years. Neither SG yield after the second year (2012) nor SG tiller density over 2 yr of the experiment suggested any stress on the SG. In the conditions evaluated in this study, overseeding CAGs into SG appears to be a viable production practice over the time frame evaluated. However, where CAGs were overseeded, later harvest dates (i.e., those occurring in mid-May or, in the case of cereal rye, in early or mid-May) were more cost effective. Additional studies are needed to evaluate the sustainability of this practice over greater time periods and in a context where grazing is used to harvest CAGs.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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## ORCID

*Patrick D. Keyser* https://orcid.org/0000-0003-0954-1789

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