Received: 17 March 2022 | Accepted: 10 June 2022

DOI: 10.1002/cft2.20184

Crop, Forage & Turfgrass Management

RESEARCH

Crop Management

# Overseed timing of ryegrass and cereal rye in soybean affects rotational crops in upstate Missouri

**Kelly A. Nelson**[1] | **Renee A. Belknap**[1] | **Derek Brake**[2] | **Gurbir Singh**[1]

[1]Division of Plant Sciences & Technology, Univ. of Missouri, Novelty, MO 63460, USA

[2]Division of Animal Sciences, Univ. of Missouri, Columbia, MO 65211, USA

**Correspondence**
Kelly A. Nelson, Univ. of Missouri, Division of Plant Sciences & Technology, Novelty, MO 63460, USA.
Email: nelsonke@missouri.edu

Assigned to Associate Editor Alexander Lindsey.

**Abstract**

Overseeding may help farmers establish cover crops (CCs) in a relay intercropping system and avoid labor and time constraints during harvest while providing grazing opportunities for integrated crop–livestock systems. This research evaluated timings (overseeded at R6, R6.5, R7, R8, and post-harvest) of cereal rye (CR; *Secale cereale* L.) and ryegrass (RG; *Lolium multiflorum* L.) CC plantings on soybean [*Glycine max* (L.) Merr.] yield, CC heights and dry mass in the spring, and the subsequent impact on rotational crop (corn [*Zea mays* L.] or soybean) yield compared with the absence of a CC (nonseeded control) and drill-seeded CC treatments following soybean harvest. Soybean light interception (LI) during the overseeding timings differed between years which along with precipitation and temperature affected fall and spring growth of grass CCs. Earlier-seeded CCs were generally taller and had greater dry mass than post-harvest seedings, depending on the year. Conventional-tilled soybean yields and the subsequent no-till soybean crop following CCs were not affected when CCs were seeded at R6.5 or later. No-till soybean yields were not affected by overseeded CCs when seeded at R6 or later; however, all CC seedings except post-harvest overseeded CCs reduced corn yields 16–33 bu acre$^{-1}$ compared with the nonseeded control. Overseeding is an option for farmers wanting to establish a CC, but risk to the intercropped and rotational crop yield occurs if seeded too early and can depend on the rotational crop.

## 1 | COVER CROPS AND OVERSEEDING

In Missouri, soybean [*Glycine max* (L.) Merr.] production since 2000 has ranged from 4.6 to 5.7 million acres, whereas corn (*Zea mays* L.) production has ranged from 2.5 to 3.7 million acres with nearly 70% of both crops raised in upstate Missouri (USDA NASS, 2021). This data indicates that nearly 30% of soybean acreage is continuous soybean which can impact pest management strategies such as herbicide-resistant weeds, soybean diseases, and nematodes along with increased risk of soil erosion with continuous soybean (Belknap & Nelson, 2022; Li et al., 2004; Liu et al., 2019; Nelson et al., 2006). Missouri farmland is exceptionally susceptible to soil erosion based on crop rotations, topography, and climate (Geist et al., 2013). Adequate residue on the soil surface can reduce erosion on most fields which may benefit from the use of cover crops especially following soybean. Residue production in Missouri for current average corn yields of 160 bu acre$^{-1}$ and soybean yields of 50 bu acre$^{-1}$ totaled approximately 9,600 and 2,500 lb acre$^{-1}$, respectively (McCarthy et al., 1993; USDA, 2021). This indicates that only 80% of the soil surface

**Abbreviations:** CC, cover crop; CR, cereal rye; LI, light interception; PAR, photosynthetically active radiation; PHDS, post-harvest drill seeded; PHOS, post-harvest overseeded; RG, ryegrass.

was covered with soybean residue, whereas more than 100% of the soil surface was covered following corn. Continuous soybean can contribute to land degradation and diversified cropping systems are needed (Liu et al., 2019, 2020). Cover crops (CCs) during the 20-wk fallow period (October–April) could improve conservation efforts in this region especially on highly erodible soils which indicates a need to encourage CC adoption following or intercropped in soybean.

Cover crops are used to improve soil properties including aggregate stability, organic matter levels, microbial activity, and improved downstream water quality (Dabney et al., 2001; Singh et al., 2018; Snapp et al., 2005). The most prevalent CCs in the Midwest are small grains (cereal rye [CR], *Secale cereale* L., wheat [*Triticum aestivum* L.]) and ryegrass (RG; *Lolium multiflorum* L.) (Wallander et al., 2021). Cover crop species selection should consider method of establishment, environmental conditions, previous herbicide use, and timing of establishment to increase adoption. Selecting a regionally adapted CC is also essential to success (Duiker, 2014). Wet autumn conditions following soybean harvest may limit establishment, growth, and survival of CCs (Baas et al., 2015; Strock et al., 2004). Conversely, dry soil conditions can also pose establishment challenges. Wilson et al. (2013) reported that if dry soil conditions existed and rain was not forecasted within 7 days of aerial seeding, alternative methods for CC establishment, such as interseeding with specialized equipment or waiting until after harvest should be considered. In addition, time constraints including fall application of dry fertilizer, manure, anhydrous ammonia, and fall tillage can affect a farmer's adoption of CCs. This narrow period of time in the autumn to plant CCs can affect adoption. Planting or overseeding CCs prior to harvest avoids interference with harvest and labor constraints, allows greater time for establishment and autumn growth, and increases opportunities for fall, winter, or spring grazing which could add direct economic value to CCs (Antosh et al., 2022; Baas et al., 2015).

Intercropping allows growing periods of two crops to overlap and increases harvestable products per unit of land area over a single crop (Lithourgidis et al., 2011). Intercropping with a CC is sensitive to local environmental conditions (Abdin et al., 1997), but it may provide improved soil health, reduce compaction, and assist in weed control (Myers et al., 2015). Intercropping CCs could also help reduce labor and equipment challenges faced in the fall with competing harvest and CC planting demands. Financial incentives (US\$12–92 acre$^{-1}$) provided by federal, state, and private organizations are a major driver of increased CC acreage especially on rented cropland (Wallander et al., 2021; Wilson et al., 2014). These programs may not cover all associated costs, and they may have long waiting lists or limitations on enrollment. Nonetheless, grazing opportunities of crop residues and CCs could increase adoption in states like Missouri with the third largest calf crop (USDA NASS, 2022) in the United States. With increasing land values, efficiency of grazing systems has become an increased focus for cattle (*Bos taurus*) producers. From 2017 to 2021, pastureland values in Missouri increased \$865 acre$^{-1}$, whereas reported pastureland values increased 12% statewide and 19–34% in upstate Missouri from 2020 to 2021 (Johnson & Massey, 2021). Because soybean residue provides minimal tonnage for grazing cattle, grass CCs such as CR or RG could offset expensive hay production and provide large increases in amounts of grazable forage to cattle. With relatively large concentrations of net energy, grass CCs are able to support maintenance or gain at considerably less cost than nearly all stored forages or in comparison to cattle fed in confinement (Drewnoski et al., 2018). Establishment of CCs as an intercropping system would also diversify cropping systems in an area that grows alot of continuous soybean and allow farmers to capture economic value from the CC. Earlier establishment of CCs through aerial overseeding could increase forage production in an integrated livestock-commodity crop production system.

**Core Ideas**

- Light interception by the soybean crop affected cover crop establishment when aerial seeded.
- Dry mass of cereal rye in spring was 55–57% greater than ryegrass.
- Soybean and corn yield was 4 and 6% higher following ryegrass than cereal rye, respectively.
- Overseeded ryegrass or cereal rye after R6.5 did not affect interseeded soybean yield.
- Corn yields were reduced 16–33 bu acre$^{-1}$ following all soybean cover crop overseeded timings.

General aerial seeding for CCs recommends overseeding when 25% of the soybean leaves are yellow, precipitation of 0.5–1.0 inches follows seeding, and careful CC species selection (Baas et al., 2015; Licht & Kaspar, 2015; Wilson et al., 2014). Aerial seeding also reduces fall tillage commonly used to establish CCs and can maintain residue coverage of the soil. Limited research is available on optimal timings to seed CCs into standing soybean in the U.S. Midwest (Adler & Nelson, 2020; Licht & Kaspar, 2015; Sandler et al., 2015). The objectives of this research were to evaluate overseeding timings of CR and RG on soybean yield, CC establishment and dry mass in the spring, and the subsequent impact on rotational crop (corn or soybean) yield.

## 2 | FIELD SITE DESCRIPTION

Field trials were established at the University of Missouri Greenley Research Center near Novelty, MO (40˚01′8.56″N, 92˚11′21.20″ W). Two separate experiments (Exp. 1: conventional tilled soybean followed by no-till soybean and Exp. 2: no-till soybean followed by no-till corn) were established in the spring of 2000 and ended in the autumn of 2001. These experiments were repeated in time and location beginning in the spring of 2001 and concluded in the autumn of 2002. Experiments were arranged as a 2-factor (2 CC species × 7 CC seeding timings) randomized complete block design with three or four replications (Table 1). All plots were 10 by 36 or 40 ft.

The first factor was CC species ('Forage Master' cereal rye seeded at 100 lb acre$^{-1}$ or 'Marshall' ryegrass seeded at 30 lb acre$^{-1}$) and the second factor was seeding timing. The seven CC seeding timings included five broadcast overseedings (Table 1) at four soybean growth stages (R6, R6.5, R7, and R8) (Fehr & Caviness, 1977) and after soybean harvest. A nonseeded control (no CC) and a post-harvest drill seeded control (Great Plains Solid Stand 10, Salina, KS) were also included in the treatment list. Overseeding CCs into soybean was accomplished using a customized 10-ft wide small seed meter attachment (International Harvester) powered by a cordless drill (DeWalt) and suspended from the shoulders of the applicator. The broadcast overseeding was performed by walking on each side of the plots to prevent damage to the narrow-row soybean. The device was calibrated to deliver 30 lb acre$^{-1}$ of RG and 100 lb acre$^{-1}$ of CR seed. Ground speed was maintained at 2.9 MPH using a metronome.

The first experiment (Table 1) was conventional-tilled soybean (Golden Harvest 3960) followed by no-till soybean (Asgrow 3701) the 2nd year. A field cultivator (John Deere 1000) was used to prepare the soil prior to drill seeding with a Great Plains Solid Stand 10 in 7.5-inch rows. The second experiment (Table 1) was no-till drilled soybean (Asgrow 3701) followed by no-till (John Deere 7000) planted corn (Burrus 671) in 30-inch wide rows. Commodity crop and CC management, seeding dates, seeding amounts, and measurements are reported in Table 1. The soil series was a Kilwinning (fine, smectitic, mesic Vertic Epiaqualf) or Putnam (fine, smectitic, mesic Vertic Albaqualf) silt loam. Experiments were in separate fields each year to allow rotation. Crops were fertilized as recommended by the Missouri Soil and Plant Testing Lab (Nathan et al., 2012). Initial soil test data are reported in Table 2.

Incident and diffused photosynthetically active radiation (PAR) measurements were obtained as a nondestructive method to measure soybean light interception (LI) and evaluate differences in crop canopy development (Dalley et al., 2004) as soybean plants matured. Three to five PAR measurements were recorded at ground level with a 3.3-ft SunScan Canopy Analysis System (Dynamax, Inc.) near solar noon positioned diagonal to four soybean rows (7.5-inch row spacing) at each overseeding timing (Table 1) in the conventional tilled, continuous soybean experiment only. Simultaneous incident PAR measurements were used to calculate LI. Light interception was the quotient of the incident PAR and ground level PAR which was then multiplied by 100.

Cover crop heights were measured prior to soybean harvest to determine how much CC foliage may be cut and processed by the combine during commodity crop harvest, in November to evaluate fall growth and cold weather tolerance of CCs for farmers interested in grazing CCs, and in spring to determine differences in growth at the time of a typical burndown herbicide application. Cover crop mass was determined using two randomly placed 1-ft$^2$ quadrats in each plot prior to the burndown herbicide application. Composite CC samples were collected from the quadrats, dried at 140 ˚F for 5–7 days, and weighed to determine dry mass. Corn heights were measured 26–35 days after planting from the soil surface to the highest point of the arch of the uppermost leaf whose tip was pointing down. Corn and soybean were harvested in the autumn using a small-plot combine (Massey 10, Kincaid Equipment Manufacturing) and yields were adjusted to 15 and 13% moisture, respectively.

Data were analyzed using the PROC GLM model using SAS v9.3 statistical program (SAS Institute, 2021) to determine significant treatment effects. Year, CC, and seeding timing were fixed effects, whereas replication was a random effect (SAS Institute, 2021). Before the analysis, variables were tested for normality of data, and based on those results, no data transformations were performed. Post hoc mean separation tests were conducted using Fisher's Protected least significant difference test ($\alpha = .05$). Data were combined over years or factors when appropriate and main effects were presented or significant interactions were reported. The LI quadratic regression analysis was performed using best-fit analysis determined with Microsoft Excel (Microsoft Office Professional Plus, 2019).

## 3 | RESULTS AND DISCUSSION

### 3.1 | Conventional tilled soybean followed by no-till soybean (Experiment 1)

Soybean canopy development is important to control annual and winter annual weeds (Dalley et al., 2004). However, establishment of CCs overseeded into soybean can be affected by precipitation (Figure 1), temperature (Figure 2), and sunlight (Figure 3) following seeding. At R6, soybean intercepted 90% of the incident PAR. Light interception decreased rapidly in 2000, but LI remained higher in 2001 which was likely due to late-season precipitation affecting leaf drop of soybean (Figure 1). This affected germination (visual observation) and height (Tables 3 and 4) of an overseeded CC. By growth stage R7, one pod on the main stem has reached its mature pod color (Fehr & Caviness, 1977); however, soybean leaves

**TABLE 1** Soybean (2000 and 2001), cover crop (CC, 2000–2001 and 2001–2002), and rotational crop (soybean or corn, 2001 and 2002) management and data collection information

| | **Experiment 1** | | **Experiment 2** | |
|---|---|---|---|---|
| | **Soybean followed by soybean** | | **Soybean followed by corn** | |
| **Management information** | **2000–2001** | **2001–2002** | **2000–2001** | **2001–2002** |
| Plot size (width by length, ft) | 10 × 40 | 10 × 36 | 10 × 40 | 10 × 40 |
| Replications | 4 | 4 | 4 | 3 |
| Soybean management year | 2000 | 2001 | 2000 | 2001 |
| Pre-plant tillage, date | Field cultivated, 30 May 2000 | Field cultivated, 2 May 2001 | No-till | No-till |
| Cultivar, planting date | Golden Harvest 3960, 15 Apr. 2000 | Golden Harvest 3960, 5 May 2001 | Asgrow 3701, 31 May 2000 | Asgrow 3701, 13 June 2001 |
| Seeding amount (seeds acre$^{-1}$) | 170,000 | 170,000 | 200,000 | 200,000 |
| Cover crop seeding date based on reproductive stage of development (Fehr & Caviness, 1977) | | | | |
| OS at R6 | 28 Aug. 2000 | 7 Sept. 2001 | 13 Sept. 2000 | 7 Sept. 2001 |
| OS at R6.5 | 12 Sept. 2000 | 14 Sept. 2001 | 18 Sept. 2000 | 14 Sept. 2001 |
| OS at R7 | 18 Sept. 2000 | 24 Sept. 2001 | 22 Sept. 2000 | 24 Sept. 2001 |
| OS at R8 | 28 Sept. 2000 | 3 Oct. 2001 | 28 Sept. 2000 | 3 Oct. 2001 |
| OS after harvest | 13 Oct. 2000 | 23 Oct. 2001 | 20 Oct. 2000 | 23 Oct. 2001 |
| Drill seeded after harvest | 13 Oct. 2000 | 23 Oct. 2001 | 20 Oct. 2000 | 23 Oct. 2001 |
| CC height measurement | 11 Oct. 2000 | 22 Oct. 2001 | 19 Oct. 2000 | 17 Oct. 2001 |
| CC height measurement | 16 Nov. 2000 | 19 Nov. 2001 | 24 Nov. 2000 | 19 Nov. 2001 |
| Harvest date | 13 Oct. 2000 | 22 Oct. 2001 | 19 Oct. 2000 | 22 Oct. 2001 |
| Soybean or corn management | Soybean in 2001 | Soybean in 2002 | Corn in 2001 | Corn in 2002 |
| CC height and mass measurement | 22 Apr. | 12 Apr. | 22 Apr. | 3 May |
| Burndown herbicide[a] | 26 Apr. | 19 Apr. | 27 Apr. | 6 May |
| Planting date | 12 June | 1 June | 27 Apr. | 16 May |
| Cultivar or hybrid | Asgrow 3701 Soybean | Asgrow 3701 Soybean | Burrus 671 Corn | Burrus 671 Corn |
| Seeding rate (seeds acre$^{-1}$) | 170,000 | 170,000 | 29,100 | 29,100 |
| Row spacing (inches) | 7.5 | 7.5 | 30 | 30 |
| Fertilizer (rate, date) | | | | |
| AN (lb N acre$^{-1}$) | na | na | 50, 9 Apr. | 50, 9 Apr. |
| N–P$_2$O$_5$–K$_2$O (lb acre$^{-1}$) | 10–50–100, 28 Apr. | 10–50–100, 28 May | 160–50–100, 28 Apr. | 160–50–100, 28 May |
| Corn height measurement | nc | nc | 1 June | 12 June |
| Harvest date | 22 Oct. | 1 Oct. | 18 Oct. | 23 Sept. |

*Note*. Ryegrass (RG) or cereal rye (CR) were overseeded (OS) at different reproductive stages of soybean development or drill seeded (DS) following harvest. AN, ammonium nitrate; na, none applied; nc, none collected.

[a] Burndown herbicide application was glyphosate (*N*-(phosphonomethyl)glycine) at 0.8–1.2 lb a.i. acre$^{-1}$ plus diamonnium sulfate at 2.5 lb acre$^{-1}$. This was followed by single or two postemergence applications of glyphosate at 0.8–1.2 lb a.i. acre plus diamonnium sulfate ($(NH_4)_2SO_4$) at 2.5 lb acre$^{-1}$ to maintain weed- and cover crop-free plots.

may remain on the plant. In 2001, the soybean canopy intercepted nearly 80% of the PAR while in 2000, LI was only 40%. Insects and disease issues can affect leaf drop of soybean (Robertson & Tylka, 1989), but none were observed in this research. In addition, plant population density and foliage diseases (data not collected) may affect leaf drop and shading until the plant is harvested. Establishing a CC too early can lead to resource competition with the intercrop (Abdin et al., 1997). For example, one study reported corn grain yield decreased when CCs were interseeded into standing corn at V2–V3, but no grain yield decrease was experienced when interseeded at or after V4 (Curran et al., 2018).

**TABLE 2** Initial soil test information for conventional tilled soybean followed by no-till soybean and no-till soybean followed by no-till corn experiments conducted from 2000 to 2001 and 2001 to 2002

| Soil test values | Experiment 1: Soybean followed by soybean | | Experiment 2: Soybean followed by corn | |
|---|---|---|---|---|
| Years | 2000–2001 | 2001–2002 | 2000–2001 | 2001–2002 |
| Soil series | Kilwinning silt loam | Putnam silt loam | Putnam silt loam | Kilwinning silt loam |
| pH (0.01 M $CaCl_2$) | 5.6 | 6.4 | 5.3 | 6.1 |
| SOM, % | 2.9 | 3.4 | 3.3 | 3.0 |
| CEC, meq 100 $g^{-1}$ | 17.0 | 11.5 | 15.5 | 13.5 |
| Bray 1P, lb $acre^{-1}$ | 43 | 53 | 54 | 65 |
| Exchangeable (1 M $NH_4AOc$) | | | | |
| K, lb $acre^{-1}$ | 310 | 270 | 340 | 310 |
| Ca, lb $acre^{-1}$ | 4,400 | 3,490 | 3,800 | 3,860 |
| Mg, lb $acre^{-1}$ | 620 | 350 | 490 | 470 |

*Note*. CEC, cation exchange capacity; SOM, soil organic matter.

**TABLE 3** Analysis of variance for overseeded ryegrass and cereal rye cover crops at different stages of soybean development seeded into conventional tilled (CT) soybean (2000, 2001) followed by no-till (NT) soybean (2001, 2002) in Experiment 1

| | CT soybean | Cover crop | | | | NT soybean |
|---|---|---|---|---|---|---|
| | 2000, 2001 | October | November | Spring | | 2001, 2002 |
| Source | Yield | Height | Height | Height | Dry mass | Yield |
| | $P > F$ | | | | | |
| Y | <.0001 | <.0001 | <.0001 | 0.1734 | 0.722 | <.0001 |
| SRS | 0.7638 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0127 |
| Y × SRS | 0.8516 | <.0001 | <.0001 | <.0001 | 0.0238 | 0.5635 |
| CC | 0.1902 | 0.0362 | 0.0014 | <.0001 | <.0001 | 0.0438 |
| Y × CC | 0.8766 | <.0001 | 0.6184 | <.0001 | 0.2598 | 0.3296 |
| SRS × CC | 0.0283 | <.0001 | 0.0771 | <.0001 | 0.2630 | 0.7578 |
| Y × SRS × CC | 0.3771 | 0.7823 | 0.0033 | <.0001 | 0.4849 | 0.2872 |

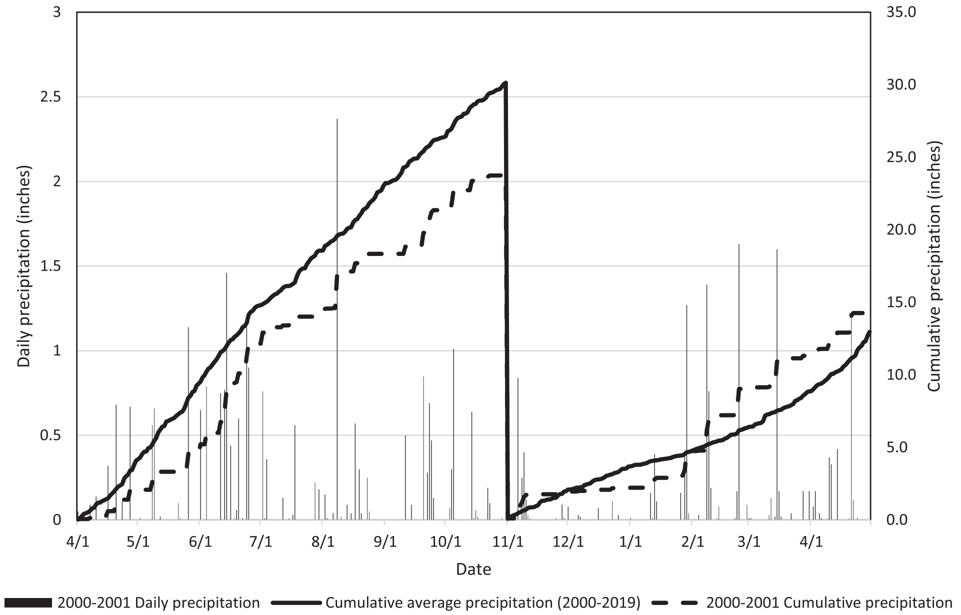
*Note*. CC, cover crop; SRS, soybean reproductive stage; Y, year.

**TABLE 4** Cover crop (CC) heights at soybean harvest (2000 and 2001) and in November

| | | | CC height in November | | | | CC height in spring | | | | Spring | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soybean | CC height in October | | 2000 | | 2001 | | 2001 | | 2002 | | Dry mass | |
| R-stage | RG | CR | RG | CR | RG | CR | RG | CR | RG | CR | 2001 | 2002 |
| | inches | | | | | | | | | | lb $acre^{-1}$ | |
| Nonseeded | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R6 | 6.4 | 5.4 | 9.0 | 7.5 | 4.1 | 4.6 | 3.3 | 10.3 | 7.0 | 6.3 | 840 | 2550 |
| R6.5 | 6.1 | 4.8 | 8.0 | 6.5 | 4.8 | 3.9 | 3.0 | 9.0 | 6.8 | 6.9 | 810 | 2570 |
| R7 | 6.2 | 5.2 | 9.0 | 7.5 | 4.9 | 3.6 | 3.0 | 9.8 | 7.0 | 5.7 | 840 | 2650 |
| R8 | 5.8 | 4.8 | 7.5 | 5.3 | 4.3 | 4.6 | 2.8 | 7.5 | 6.9 | 6.1 | 550 | 2320 |
| PHOS | 0 | 0 | 3.0 | 4.3 | 3.7 | 2.8 | 0 | 6.3 | 5.4 | 5.6 | 480 | 1560 |
| PHDS | 0 | 0 | 3.0 | 4.0 | 4.2 | 3.2 | 0 | 6.0 | 7.1 | 6.1 | 730 | 1830 |
| LSD ($P = .05$) | 0.6 | | 1.3 | | | | 1.4 | | | | 420 | |

*Note*. Cover crop heights and dry mass were obtained prior to spring burndown herbicide application. Cover crops (ryegrass [RG] and cereal rye [CR]) were seeded into conventional tilled soybean in 2000 and 2001 followed by no-till soybean in 2001 and 2002 for Exp. 1. LSD, least significant difference; PHDS, post-harvest drill seeded; PHOS, post-harvest overseed; R-stage, reproductive stage of development (Fehr & Caviness, 1977) when cover crops were over seeded.

**(a)** 2000-2001



**(b)** 2001-2002

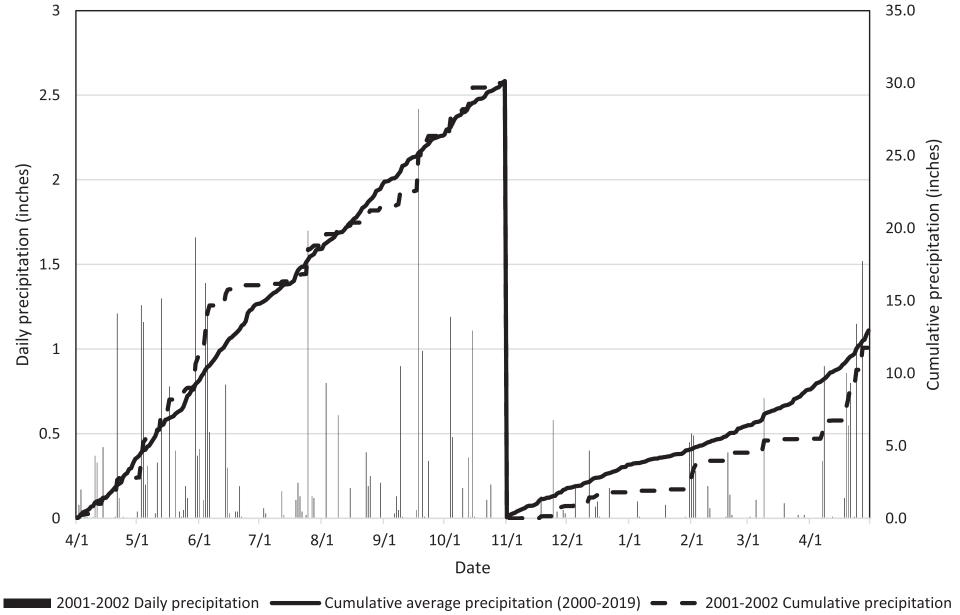


**FIGURE 1** Daily precipitation (bars), cumulative 20-year average precipitation (solid line), and cumulative growing season precipitation (dash line) for the intercropped commodity crop (1 Apr.–30 Oct.) and cover crop seasons (1 Nov.–1 May) in the (a) 2000–2001 and (b) 2001–2002 growing seasons

However, we hypothesized that there would be no impact on soybean yield similar to other research (Peterson et al., 2019).

A significant interaction ($P = .0283$) between CC species and seeding timing on conventional-tilled soybean yield was observed in this experiment (Table 3). Soybean yields were 3 bu acre$^{-1}$ greater in the absence of a CC seeded or with CC seeded after soybean harvest compared with soybean with CCs seeded at R6 (Figure 4). All overseeding timings at or after R6.5 did not affect soybean yields of conventional-tilled soybean. Overseeding CCs into soybean with conventional tillage may allow greater CC seed-to-soil contact and improve CC establishment which may result in greater interference with soybean yield late in the season in a year when precipitation was reduced compared with the 20-year average (Figure 1a). At harvest, CCs were 6.4–6.8 inches tall, which could be cut while harvesting the commodity crop because harvest heights of draper and screw conveyor heads may range from 3.2 to 3.8 inches above the soil surface depending

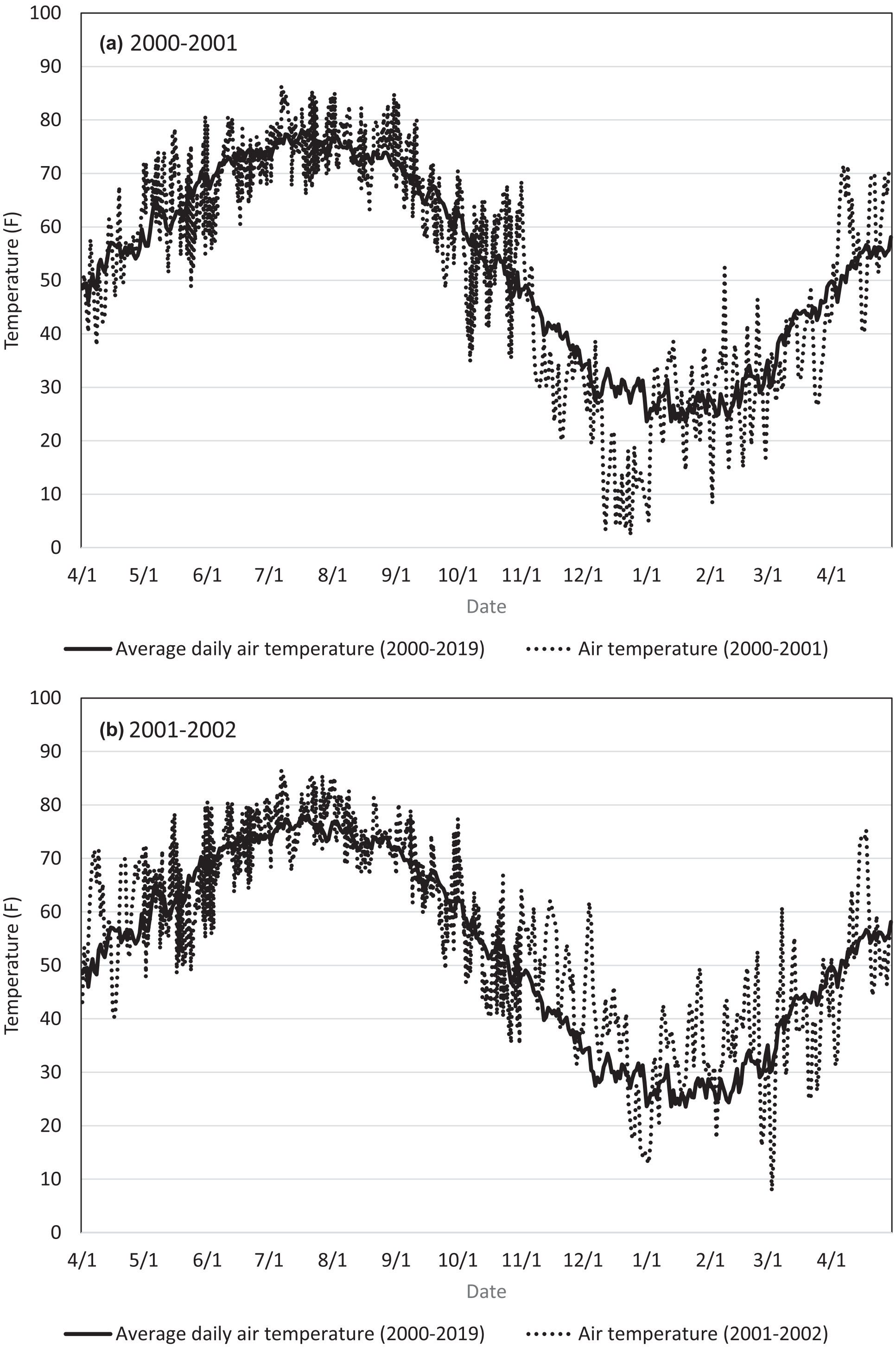


**FIGURE 2** Average daily air temperature (solid line) from 2000 to 2019 and daily average air temperature from (a) 2000–2001 and (b) 2001–2002 represented by the dotted line

on the ground speed at harvest (de Menezes et al., 2018). Although it hasn't been a major issue during harvest, guttation droplets on the grass CCs and dew may persist longer in the morning and appear earlier in the evening when harvesting soybean with an overseeded CC (personal observation, 2001 and 2002). Cover crop heights were different in November and the spring depending on the year (Tables 3 and 4). This was evident because CCs seeded at R6–R7 were tallest (6.5–9.0 inches) compared with later seeding dates in November 2000, whereas minimal differences in heights among seeding dates were observed in November 2001 (Table 4). Cover crops were sprayed with a burndown herbicide application in the spring (Table 1) when plants were <10 inches tall to minimize the impact of the CC on the rotational crop. In the spring,

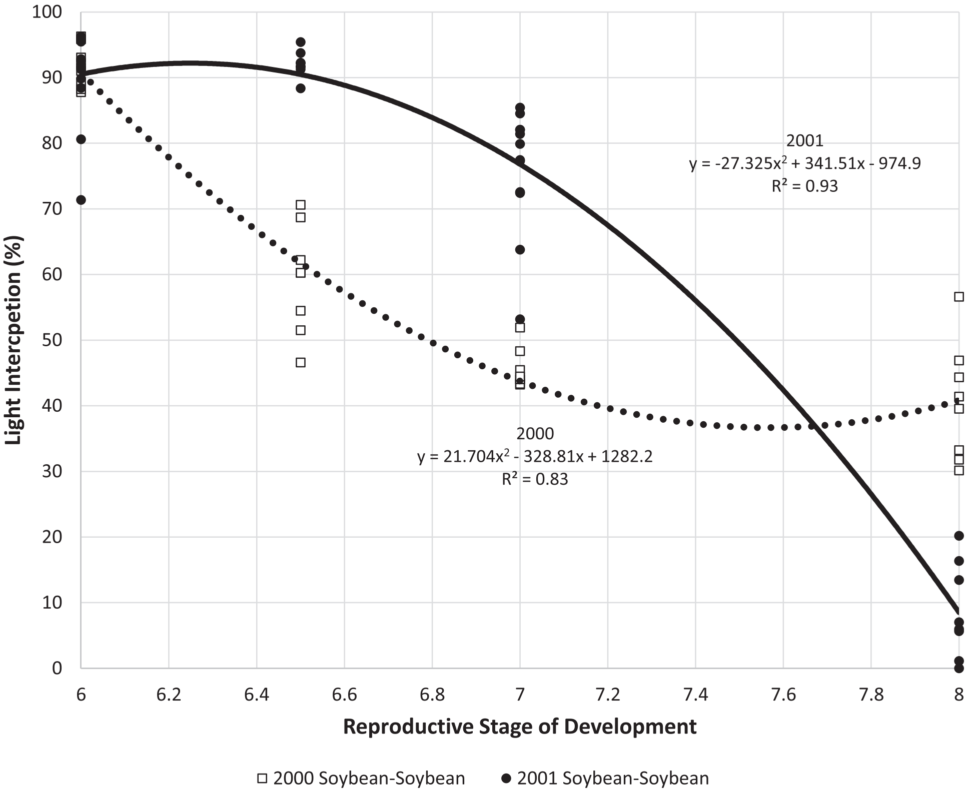


**FIGURE 3** Light interception at different reproductive stages (Fehr & Caviness, 1977) of conventional tilled soybean development in 2000 (dotted line) and 2001 (solid line) at the time of overseeding cover crops in Exp. 1. Squares (2000) and dots (2001) represent average light interception values in each replication of the overseeded ryegrass and cereal rye plots for individual measurements from each replication

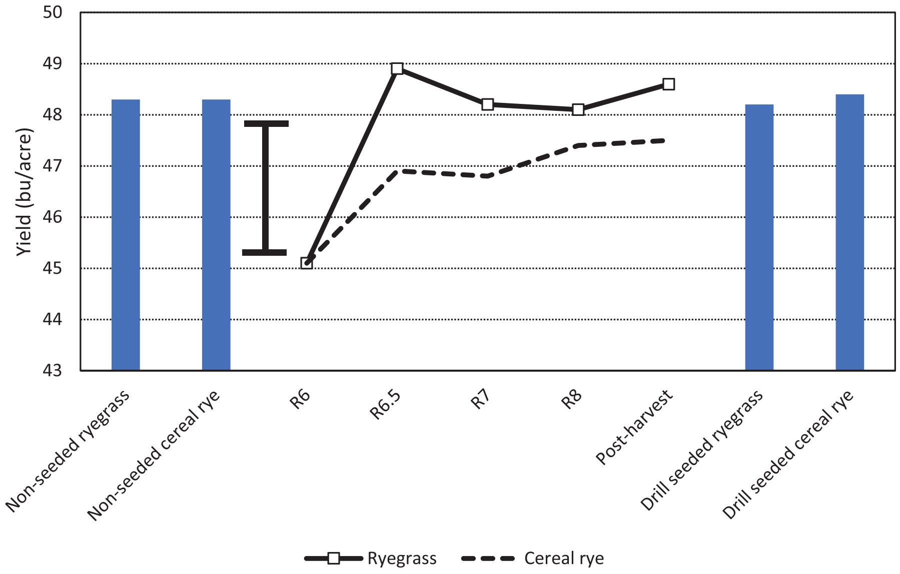


**FIGURE 4** No-till soybean yield response to overseeded seeded ryegrass (solid line) or cereal rye (dotted line) from R6 (Fehr & Caviness, 1977) to post-harvest in 2000 and 2001 in Exp. 1. Bars represent soybean yields of control with no cover crop (nonseeded on the left) and yields for cover crops drill seeded after soybean harvest (right). Whiskers represent the least significant difference ($P = .05$) = 2.7 bu acre$^{-1}$

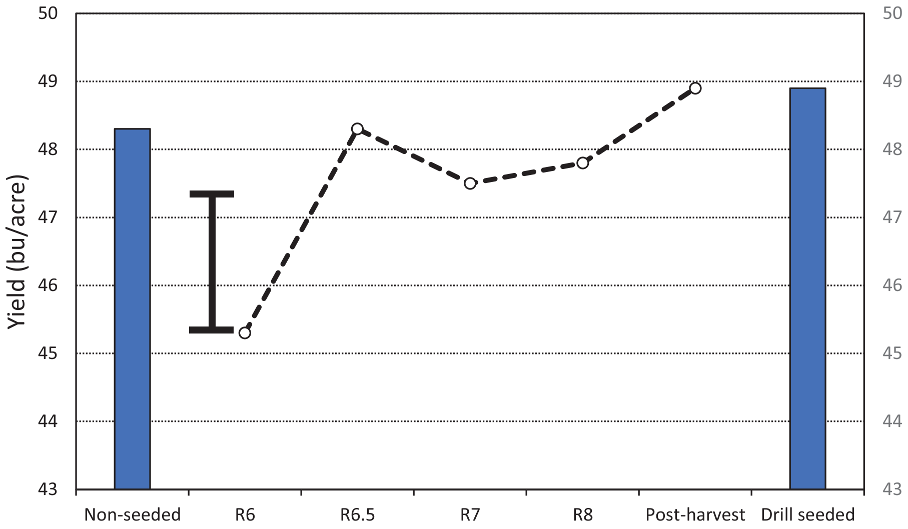


**FIGURE 5** Soybean yield following overseeded cover crops at different stages of soybean development (Fehr & Caviness, 1977) in Exp. 1. Whiskers represent the least significant difference ($P = .05$) = 2.0 bu acre$^{-1}$. Data were combined over cover crop species and years. Bars represent nonseeded soybean grain yields and drill seeded grain yields. Following ryegrass (48.4 bu acre$^{-1}$), soybean yields were significantly greater than following cereal rye (47.3 bu acre$^{-1}$). Yield from control with no cover crop (right bar) and from drilled after soybean harvest (left bar)

overseeded RG was taller than post-harvest overseeded (PHOS) or post-harvest drill seeded (PHDS) in 2001, but overseeded RG at all timings was a similar height compared with PHDS in 2002. Overseeded CR height evaluated in the spring was taller than RG and later seeded CR (>R8) in 2001, but heights were similar in 2002.

Spring CC dry mass was significantly greater ($P < .0001$) (Table 3) when overseeded with CR (1,620 lb acre$^{-1}$) compared with RG (700 lb acre$^{-1}$) (Table 4). There was a significant interaction between year and CC ($P < .0001$) with all dry mass values in 2002 greater than 2001. The soil series in 2001 was a Putnam silt loam with poor surface drainage which could have affected cold tolerance of RG (Wingler & Hennessy, 2016) along with colder air temperatures (December 2000–January 2001) compared with the 20-year average (Figure 2). This may have affected RG persistence in 2000 compared with 2001 especially when seeded later in the autumn. Overall, CC dry mass was similar (480–820 lb acre$^{-1}$) in 2001 (Table 4). In 2002, CC dry mass was 490–1,090 lb acre$^{-1}$ greater with CCs overseeded into standing soybean compared with PHOS or PHDS (Table 4). This indicates that overseeding timing can increase biomass production compared with post-harvest drill seeding. In upstate Missouri, diversified crop–livestock farms are common. Dry mass of CR and RG may be used as a supplemental forage for spring grazing to reduce reliance on hay resources (Dhakal et al., 2022); however, differences in timing of grazing can substantially influence the nutritive value of forage and animal performance among cattle grazing autumn planted cool-season annual grasses as CC during spring (Drewnoski et al., 2018).

Soybean yields following RG (49.4 bu acre$^{-1}$) were significantly greater ($P = .0127$) than CR (47.3 bu acre$^{-1}$) when data were averaged over all of the seeding timings (Table 3). Soybean following early seeded CCs had slightly lower yields (45.3 bu acre$^{-1}$) compared with all other timings (47.5–48.9 bu acre$^{-1}$) (Figure 5). The soil in the early-seeded CC treatment may have been cooler and wetter which could promote seedling diseases and seed treatments may need to be recommended in higher residue systems. This research also shows that seeding CCs too early may affect yields of the intercrop (conventional-tilled soybean) and the rotational crop which was unlike research in the upper Midwest that indicated no impact on soybean yield when seeded at the R4 or R6 stages of soybean development (Peterson et al., 2019). Our research indicates soybean at the R6 stage of development may be susceptible to interference from the CC for water and nutrient resources.

### 3.2 | No-till soybean followed by no-till corn (Experiment 2)

Ryegrass or CR ($P = .7613$) overseeded or drill seeded after soybean harvest had no effect ($P = .3650$) on no-till soybean yields (Table 5). Cover crop height at harvest was affected by seeding timing and the PHDS or PHOS establishment method (Tables 5 and 6). Cover crop heights were generally shorter at harvest (0.2–3.8 inches) in a long-term, no-till field indicating that minimal CC biomass would enter the combine using a draper or screw auger head (de Menezes et al., 2018). However, canopy development differences between cultivars

**TABLE 5** Analysis of variance for ryegrass and cereal rye cover crops seeded into no-till (NT) soybean (2000, 2001) followed by NT corn (2001, 2002) in Experiment 2

| | NT soybean (2000, 2001) | Cover crop (2000–2001, 2001–2002) | | | | NT corn (2001, 2002) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Source | Yield | October Height | November Height | Spring Height | Spring Dry mass | Population | Height | Moisture | Yield |
| | *P* > *F* | | | | | | | | |
| Yr | <.0001 | .243 | .1722 | <.0001 | .0128 | .2108 | <.0001 | <.0001 | <.0001 |
| SRS | .7613 | <.0001 | <.0001 | <.0001 | <.0001 | .0200 | .0003 | .0026 | <.0001 |
| Yr × SRS | .9375 | .0002 | <.0001 | <.0001 | .0003 | .3323 | .0952 | .0002 | .2508 |
| CC | .3650 | .0576 | <.0001 | <.0001 | <.0001 | .8182 | .0008 | .3966 | .0319 |
| Yr × CC | .1743 | .8394 | .0096 | <.0001 | .1694 | .1617 | .7314 | .5345 | .0890 |
| SRS × CC | .7175 | .0439 | .0042 | <.0001 | .0774 | .4515 | .1679 | .1882 | .5791 |
| Yr × SRS × CC | .9101 | .4428 | .1167 | .0001 | .5462 | .2768 | .9169 | .6680 | .3517 |

*Note*. CC, cover crop; SRS, soybean reproductive stage; Yr, year.

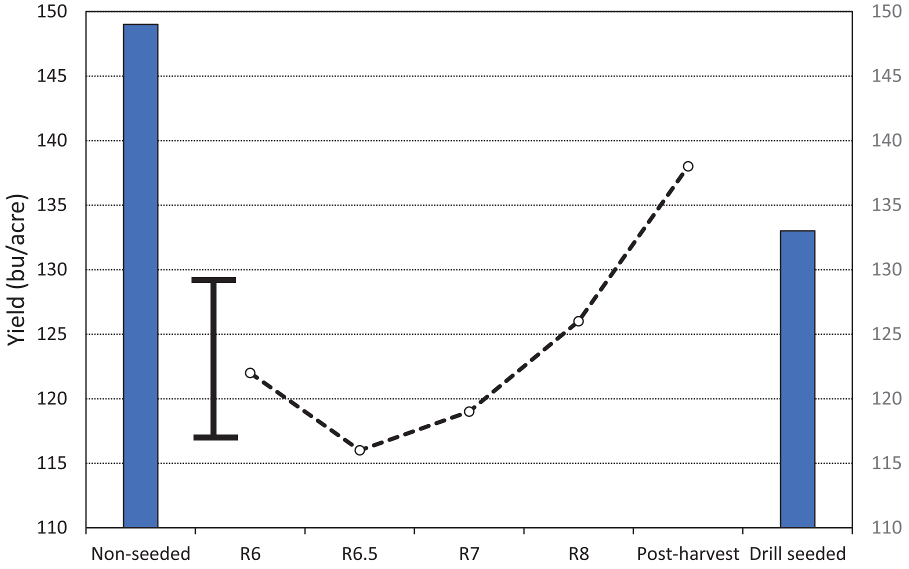


**FIGURE 6** No-till corn grain yield response to cover crops overseeded into soybean the previous year at R6, R6.5, R7, R8 stages of development (dashed line), and drilled post-harvest (right bar) after harvesting soybean in Exp. 2. Data were combined over years (2001 and 2001) and cover crop species (winter rye and ryegrass) treatments. Least significant difference ($P = .05$) value was 13 bu acre$^{-1}$. Left bar is the control with no cover crop

in this research compared with the conventional tilled site (Experiment 1) discussed above could affect CC establishment and growth as indicated by the height measurements in November (28–80 days after CC seeding) (Table 6). Cover crop height in November, when autumn grazing could occur, was 0–6.3 inches taller in RG seeded from R6 to R8 compared with CR. Plant heights at the November sampling date (28–36 days after planting) were similar between CR and RG when seeded after soybean harvest. The burndown herbicide was applied when CCs were <9 inches tall. In the spring of 2001, CR was taller than RG at all seeding dates indicating poor winter survival of RG especially when it was seeded at R8 or later. Again, the soil series (Putnam silt loam) had a 0–1% slope with poor surface water drainage along with colder air temperatures (December 2000–January 2001, Figure 1a) which likely affected winter survival (personal observation, 2001) of RG (Wingler & Hennessy, 2016). Adler et al. (2020) reported CC biomass was affected by landscape position with both drill and overseeded CC in a similar crop rotation, with lowest CC establishment in flatter, wetter field areas of the field. However, CC plant height was similar among CC species for all seeding dates in the spring of 2002. This site was a Kilwinning silt loam with 2–3% slope and better surface water drainage.

**TABLE 6** Cover crop (CC) height at soybean harvest (2000 and 2001), in November 2000 and 2001, and in April (2001 and 2002) prior to burndown herbicide application in Experiment 2

| CC height | | CC height in | | CC height in April | | | | | CC April | | | | Corn grain | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soybean at harvest | | November | | 2001 | | 2002 | | | dry mass | | Corn plant | Corn | moisture | |
| R-stage | RG | CR | RG | CR | RG | CR | RG | CR | 2001 | 2002 | population | height | 2001 | 2002 |
| | inches | | | | | | | | lb acre$^{-1}$ | | no. acre$^{-1}$ | inches | % | |
| Nonseeded | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26,300 | 10.9 | 16.2 | 22.6 |
| R6 | 3.8 | 3.6 | 6.3 | 4.5 | 3.0 | 7.7 | 7.8 | 6.7 | 1080 | 2800 | 24,400 | 9.1 | 15.8 | 25.3 |
| R6.5 | 3.1 | 3.9 | 6.3 | 5.0 | 3.2 | 9.0 | 7.1 | 7.2 | 1120 | 2490 | 24,100 | 8.7 | 15.8 | 25.8 |
| R7 | 2.7 | 3.6 | 5.2 | 4.5 | 3.2 | 7.7 | 7.3 | 7.0 | 1030 | 2250 | 23,900 | 9.3 | 15.7 | 25.3 |
| R8 | 0.2 | 0 | 4.6 | 0 | 0.5 | 5.2 | 6.3 | 6.5 | 330 | 2010 | 24,000 | 9.4 | 16.1 | 24.4 |
| PHOS | 0 | 0 | 3.1 | 2.9 | 0 | 4.5 | 4.8 | 6.0 | 780 | 1600 | 26,100 | 9.7 | 15.7 | 23.5 |
| PHDS | 0 | 0 | 3.3 | 3.5 | 0 | 5.5 | 5.8 | 6.6 | 1260 | 1020 | 26,700 | 10.2 | 16.0 | 25.0 |
| LSD (*P* = .05) | 0.5 | | 0.7 | | 1.2 | | | | 700 | | 2,200 | 0.9 | 1.1 | |

*Note*. Dry mass was harvested prior to burndown herbicide application. Corn plant population was combined over CCs and years. CR, cereal rye; LSD, least significant difference; PHDS, post-harvest drill seeded; PHOS, post-harvest overseed; RG, ryegrass; R-stage, reproductive stage of development (Fehr & Caviness, 1977) when cover crops were overseeded.

Dry mass of cereal rye (1,650 lb acre$^{-1}$) was significantly ($P < .0001$) greater than ryegrass dry mass (750 lb acre$^{-1}$) in the spring prior to a burndown herbicide application when data were averaged over seeding timings (Table 5). Cover crop dry mass was generally greater in 2001 compared with 2002 except for drill-seeded CCs in 2001. Cover crops seeded from R6 to R7 had the greatest dry mass (1,030–1,120 lb acre$^{-1}$) in 2001 and (2,250–2,800 lb acre$^{-1}$) in 2002 as did PHDS CCs in 2001. Greater CC heights and biomass production appeared to reduce corn plant population and plant heights. Similarly, differences in grass CC genotypes and to a lesser extent CC biomass were noted to reduce corn plant populations and yields (Kaspar & Bakker, 2015).

There was no significant difference ($P = .8182$) between corn plant populations following CR (25,200 plants acre$^{-1}$) or RG (24,900 plants acre$^{-1}$) in this experiment. Corn plant populations were reduced by the grass CCs seeded in this research from R6.5 to R8 compared with the absence of a CC. Corn plants were slightly taller ($P = .0008$) following RG (10.0 inches) compared with CR (9.2 inches), which persisted up to 60 days after planting (data not presented).

When corn grain yields were averaged over seeding timing (Table 5), corn grain yield following RG was 133 bu acre$^{-1}$, which was more than 6% ($P = .0319$) greater than corn following CR (125 bu acre$^{-1}$). The control with no CC had the greatest overall corn yields (149 bu acre$^{-1}$) compared with other CC seeding timings and methods following soybean (Figure 6). Grass CCs reduced corn yields 8–22% compared with the nonseeded control. Nitrogen rate and timing may have impacted the results in this research because 50 lb N acre$^{-1}$ was applied early pre-plant followed by 160 lb N acre$^{-1}$ at planting or prior to corn emergence (Table 1). Adjustments in N rates and timing could help optimize corn yield when grass cover crop residue is present. Earlier overseeding dates of grass CCs that were taller and had greater dry mass production (Table 6) reduced corn grain yields compared with post-harvest or drill-seeded CCs. A reduction in corn yield following grass CCs (Adler et al., 2020; Kaspar & Bakker, 2015; Quinn et al., 2021) is a risk that farmers and practitioners should be aware of and provide recommendations on how to manage and avoid the risk of yield loss.

## 4 | CONCLUSIONS

Effective systems that promote early CC emergence as a relay intercrop production system are essential for establishing a CC and promoting conservation goals. Establishment of CCs using aerial seeding methods are affected by climatic conditions such as temperature and water (Baskin & Baskin, 1988; Gummerson, 1986; Tribouillois et al., 2016), planting method of the commodity crop, CC species (Noland et al., 2018), and CC seed size (Wilson et al., 2014). Typically, greater CC seeding rates (25–50%) are recommended for aerial seeding (Baas et al., 2015; Licht & Kaspar, 2015) compared with drill-seeded and were used in this research. This increases seed and seeding costs with aerial seeding and the risk of yield loss to the overseeded soybean crop could be impacted based on our research. Our research indicates CC seeding rates may need to be reduced at early seeding timings (R6) to reduce the risk of yield loss to the interseeded soybean crop. This may also reduce the cost of the CC treatment and the subsequent impact on the rotational crop. Effective management strategies for CC establishment following soybean are needed to meet conservation goals and forage production opportunities for integrated crop–livestock farmers. Intercropping grass CCs by overseeding in soybean was clipped and processed by the combine at harvest depending on weather and tillage between the two experiments. Tillage systems also affected establishment of CCs between the two experiments. Light interception of soybean from R6 to harvest was affected by conditions in the autumn which in turn affected autumn growth and establishment of the CC. Overseeding timing and CC species reduced conventional-tilled soybean yields and rotational crop yields depending on how early CCs were established and environmental conditions following seeding. In no-till soybean, there was no effect of seeding timing on intercropped soybean grain yields. Seeding date and CC species affect on heights and dry mass production depended on autumn and winter environmental condtions. Dry mass of CR was 55–57% greater than RG due to greater winter hardiness (Dhakal et al., 2022) which indicates it is a superior CC compared with RG in this region unless a farmer is rotating to corn. Rotational crop yields (corn or soybean) were not enhanced with RG or CR CCs compared with the absence of a CC. Overseeding grass CCs after R6.5 soybean is recommended to avoid risk of yield loss. Soybean yields following RG were 4% greater than CR, whereas corn yields following RG were 6% greater than CR. The risk of grass CCs evaluated in this research reducing corn grain yield (8–22%) was observed at all seeding timings except overseeded CCs at harvest which probably provided the poorest protection from soil erosion based on dry mass values. Earlier CC seeding dates would allow farmers to diversify cropping systems and integrate crop–livestock production systems to gain economic benefits from CCs. Understanding risks and improving CC establishment consistency in a soybean intercropping system will help encourage farmer adoption. In the future, additional research should evaluate reduced seeding rates of overseeded CCs on current and rotational crops in the presence and absence of grazing because CCs alone did not increase short-term yields of the rotational crop.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## ORCID

*Kelly A. Nelson* https://orcid.org/0000-0001-8334-7488

## REFERENCES

Abdin, O. A., Coulman, B. E., Cloutier, D. C., Faris, M. A., & Smith, D. L. (1997). Establishment, development and yield of forage legumes and grasses as cover crops in grain corn in eastern Canada. *Journal of Agronomy and Crop Science*, *179*, 19–27. https://doi.org/10.1111/j.1439-037X.1997.tb01143.x

Adler, R. L., & Nelson, K. A. (2020). Overseeding cover crops on corn and soybean response in upstate Missouri. *Crop, Forage & Turfgrass Management*, *2020*, 6e20037. https://doi.org/10.1002/cft2.20037

Adler, R. L., Singh, G., Nelson, K. A., Weirich, J., Motavalli, P. P., & Miles, R. J. (2020). Cover crop impact on crop production and nutrient loss in a no-till terrace topography. *Journal of Soil and Water Conservation*, *75*, 153–165. https://doi.org/10.2489/jswc.75.2.153

Antosh, E., Liebig, M. A., Archer, D. W., & Luciano, L. (2022). Cover crop interseeding effects on aboveground biomass and corn grain yield in western North Dakota. *Crop, Forage, & Turfgrass Management*, *8*, e20148. https://doi.org/10.1002/cft2.20148

Baas, D. S. C., Clay, D., Clay, S., Gross, P., Hoorman, J., Hoormann, R., Kaspar, T., Kladivko, E., Ruark, M., Millar, N., Murray, H., Noggle, S., & Wyse, D. (2015). Integrating cover crops in soybean rotations: Challenges and recommendations for the north central region. *Midwest Cover Crops Council*, https://midwestcovercrops.org/wp-content/uploads/2016/10/ALL_2015_Integrating-cover-crops-in-soybean-rotations.pdf

Baskin, C. C., & Baskin, J. M. (1988). Germination ecophysiology of herbaceous plant species in a temperate region. *American Journal of Botany*, *75*, 286–305. https://doi.org/10.2307/2443896

Belknap, R. A., & Nelson, K. A. (2022). Long-term reduced tillage and no-till cropping systems affect claypan soil properties and soybean cyst nematode. *Agronomy Journal*, https://doi.org/10.1002/agj2.21140

Curran, W. S., Hoover, R. J., Mirsky, S. B., Roth, G. W., Ryan, M. R., Ackroyd, V. J., Wallace, J. M., Dempsey, M. A., & Pelzer, C. J. (2018). Evaluation of cover crops drill interseeded across the Mid-Atlantic region. *Agronomy Journal*, *110*, 435–443. https://doi.org/10.2134/agronj2017.07.0395

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, *32*(7–8), 1221–1250. https://doi.org/10.1081/CSS-100104110

Dalley, C. D., Kells, J. J., & Renner, K. A. (2004). Effect of glyphosate application timing and row spacing on corn (*Zea mays*) and soybean (*Glycine max*) yields. *Weed Technology*, *18*, 165–176.

de Menezes, P. C., da Silva, R. P., Carneiro, F. M., da, S., Girio, L. A., de Oliveira, M. F., & Voltarelli, M. A. (2018). Can combine headers and travel speeds affect the quality of soybean harvesting operations? *Revista Brasileira de Engenharia Agrícola e Ambiental*, *22*, 732–738. https://doi.org/10.1590/1807-1929/agriambi.v22n10p732-738

Dhakal, D., Erwin, Z. L., & Nelson, K. A. (2022). Grazing cover crops in a no-till corn and soybean rotation. *Agronomy Journal*, *114*, 1255–1268. https://doi.org/10.1002/agj2.20999

Drewnoski, M., Parsons, J., Blanco, H., Redfearn, D., Hales, K., & MacDonald, J. (2018). Forages and pastures symposium: Cover crops in livestock production: Whole-system approach. Can cover crops pull double duty: Conservation and profitable forage production in the Midwestern United States? *Journal of Animal Science*, *96*, 3503–3512. https://doi.org/10.1093/jas/sky026

Duiker, S. W. (2014). Establishment and termination dates affect fall-established cover crops. *Agronomy Journal*, *106*, 670–678. https://doi.org/10.2134/agronj2013.0246

Fehr, W. R., & Caviness, C. E. (1977). *Stages of soybean development* (Iowa State University Extension Publication no. 80). Iowa State University.

Geist, L., Scharf, P., Myers, B., & Guinan, P. (2013). *Topsoil lost to rainfall costs farmers money erosion of topsoil can permanently reduce farmland productivity* (University of Missouri Extension Publication). University of Missouri.

Gummerson, R. J. (1986). The effect of constant temperatures and osmotic potentials on the germination of sugar beet. *Journal of Experimental Botany*, *37*, 729–741. https://doi.org/10.1093/jxb/37.6.729

Johnson, K., & Massey, R. (2021). *Survey finds Missouri land values increased across the board in 2021* (University of Missouri Extension Publication). University of Missouri.

Kaspar, T. C., & Bakker, M. G. (2015). Biomass production of 12 winter cereal cover crop cultivars and their effect on subsequent no-till corn yield. *Journal of Soil and Water Conservation*, *70*, 353–364. https://doi.org/10.2489/jswc.70.6.353

Li, J., Smeda, R. J., Nelson, K. A., & Dayan, F. E. (2004). Physiological basis for resistance to diphenyl ether herbicides in common waterhemp (*Amaranthus rudis*). *Weed Science*, *52*, 333–338. https://doi.org/10.1614/WS-03-162R

Licht, M., & Kaspar, T. C. (2015). *Tips and considerations for getting started with cover crops* (Integrated Crop Management News Publication 823). Iowa State University Extension. https://crops.extension.iastate.edu/cropnews/2015/08/tips-and-considerations-getting-started-cover-crops

Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., & Vlachostergios, D. N. (2011). Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, *5*, 396–410.

Liu, Z., Liu, J., Yu, Z., Yao, Q., Li, Y., Liang, A., Zhang, W., Mi, G., Jin, J., Liu, X., & Wang, G. (2020). Long-term continuous cropping of soybean is comparable to crop rotation in mediating microbial abundance, diversity and community composition. *Soil and Tillage Research*, *197*, 104503. https://doi.org/10.1016/j.still.2019.104503

Liu, J., Yao, Q., Li, Y., Zhang, W., Mi, G., Chen, Y. u. Z., & Wang, G. (2019). Continuous cropping of soybean alters the bulk and rhizospheric soil fungal communities in a mollisol of Northeast China. *Land Degradation and Development*, *30*, 725–1738. https://doi.org/10.1002/ldr.3378

McCarthy, J. R., Pfost, D. L., & Currence, H. D. (1993). *Conservation tillage and residue management to reduce soil erosion* (G1650). University of Missouri.

Myers, R., Ellis, C., Hoormann, R., Reinbott, T., Kitchen, N., & Reisner, J. (2015). *Cover crops in Missouri: Putting them to work on your farm* (Extension Publication G4161). University of Missouri Extension.

Nathan, M., Stecker, J. A., & Sun, & Y. (2012). *Soil testing in Missouri*. Division Plant Science, College of Agriculture, Food, and Natural Resources.

Nelson, K. A., Johnson, W. G., Wait, J. D., & Smoot, R. L. (2006). Winter annual weed management in corn (*Zea mays*) and soybean (*Glycine max*) and the impact on soybean cyst nematode (*Heterodera glycines*) egg population densities. *Weed Technology*, *20*, 965–970. https://doi.org/10.1614/WT-05-119.1

Noland, R. L., Wells, M. S., Sheaffer, C. C., Baker, J. M., Martinson, K. L., & Coulter, J. A. (2018). Establishment and function of cover crops interseeded into corn. *Crop Science*, *58*, 863–873. https://doi.org/10.2135/cropsci2017.06.0375

Peterson, A. T., Berti, M. T., & Samarappuli, D. (2019). Intersowing cover crops into standing soybean in the US Upper Midwest. *Agronomy*, *9*, 264. https://doi.org/10.3390/agronomy9050264

Quinn, D. J., Poffenbarger, H. J., Leuthold, S. J., & Lee, C. D. (2021). Corn response to in-furrow fertilizer and fungicide across rye covercrop termination timings. *Agronomy Journal*, *113*, 3384–3398. https://doi.org/10.1002/agj2.20723

Robertson, A., & Tylka, G. (1989). *Common soybean leaf diseases and soybean rust*. Iowa State University Extension. https://crops.extension.iastate.edu/files/article/PM1989.pdf

Sandler, L. N., Nelson, K. A., Dudenhoeffer, C. J., Miles, R. J., & Motavalli, P. P. (2015). Effect of radish overseeded planting date on interseeded soybean and corn yield. *Crop, Forage, & Turfgrass Management*, *1*(1), 1–10. https://doi.org/10.2134/cftm2015.0119

SAS Institute. (2021). *SAS 9.3*. SAS Institute.

Singh, G., Schoonover, J. E., & Williard, K. W. (2018). Cover crops for managing stream water quantity and improving stream water quality of non-tile drained paired watersheds. *Water*, *10*, 521. https://doi.org/10.3390/w10040521

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. M., Leep, R., & O'Neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy Journal*, *97*, 322–332. https://doi.org/10.2134/agronj2005.0322a

Strock, J. S., Porter, P. M., & Russelle, M. P. (2004). Cover cropping to reduce nitrate loss through subsurface drainage in the northern US Corn Belt. *Journal of Environmental Quality*, *33*, 1010–1016. https://doi.org/10.2134/jeq2004.1010

Tribouillois, H., Dürr, C., Demilly, D., & Wagner, M. H., & Justes, E. (2016). Determination of germination response to temperature and water potential for a wide range of cover crop species and related functional groups. *PLOS ONE*, *11*, 1–16. https://doi.org/10.1371/journal.pone.0161185

USDA NASS. (2021). *Missouri crop report*. USDA NASS. https://www.nass.usda.gov/Statistics_by_State/Missouri/Publications/Press_Releases/2021/20211109-MO-November-Crop-Production.pdf

USDA NASS. (2022). *Cattle*. USDA NASS. https://downloads.usda.library.cornell.edu/usda-esmis/files/h702q636h/pn89f870n/jw828f69f/catl0122.pdf

Wallander, S. D. S., Bowman, M., & Claassen, R. (2021). *Cover crop trends, programs and practices in the United States*. USDA ERS.

Wilson, M. L., Allan, D. L., & Baker, J. M. (2014). Aerially seeding cover crops in the northern US Corn Belt: Limitations, future research needs, and alternative practices. *Journal of Soil and Water Conservation*, *69*(3), 67A–72A. https://doi.org/10.2489/jswc.69.3.67A

Wilson, M. L., Baker, J. M., & Allan, D. L. (2013). Factors affecting successful establishment of aerially seeded winter rye. *Agronomy Journal*, *105*, 1868–1877. https://doi.org/10.2134/agronj2013.0133

Wingler, A., & Hennessy, D. (2016). Limitation of grassland productivity by low temperature and seasonality of growth. *Frontiers in Plant Science*, *7*, 1130. https://doi.org/10.3389/fpls.2016.01130

**How to cite this article:** Nelson, K. A., Belknap, R. A., Brake, D., & Singh, G. (2022). Overseed timing of ryegrass and cereal rye in soybean affects rotational crops in upstate Missouri. *Crop, Forage & Turfgrass Management*, *8,* e20184. https://doi.org/10.1002/cft2.20184