OVERSEEDING ANNUAL RYEGRASS AND CEREAL RYE INTO SOYBEAN FOR WINTER FORAGE AND AS A COVER CROP FOR WEED CONTROL AND SOIL CONSERVATION

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by

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The undersigned appointed by the Dean of the Graduate School, have examined the thesis entitled.

OVERSEEDING ANNUAL RYEGRASS AND CEREAL RYE INTO SOYBEAN FOR WINTER FORAGE AND AS A COVER CROP FOR WEED CONTROL AND SOIL CONSERVATION

Presented by Luke Smith

A candidate for the degree of Master of Science.

And hereby certify that in their opinion it is worthy of acceptance.

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ABSTRACT

Annual ryegrass (*Lolium multiflorum* Lam.) and cereal rye (*Secale cereale* L.) are two forages that fit well into mixed row crop/livestock operations as they can be used both as a cover crop and as a source of winter pasture. Few researchers have studied how to integrate these forages in a soybean [*Glycine max* (L.) Merrill]-winter pasture-corn (*Zea mays* L.) rotation. An experiment was conducted where each of these forage species was overseeded at different stages of soybean development, and corn was grown as a subsequent crop.

Soybean yield was not altered by overseeding annual ryegrass or cereal rye. All treatments yielded over 2,500 kg ha^{-1} for the season (with a high of 4,200 kg ha^{-1}), which would supply much needed pasture for winter grazing. While all treatments were adequate sources of forage, overseeding at the R 6.5 stage consistently produced the greatest yields for both annual ryegrass and cereal rye. Forage quality from annual ryegrass was slightly better than for cereal rye, but both had crude protein levels of more than 170 g kg^{-1} and neutral detergent fiber of less than 559 g kg^{-1}. The overseeded treatments had at least 60% more residue cover and at least 70% less weed cover than did the control plots. Corn yield in the following year was not altered by overseeding. The results of the experiment demonstrate that livestock operations in the lower Midwest could use cereal rye and annual ryegrass overseeded into soybean for winter grazing.

Chapter 1

INTRODUCTION

Missouri has the second largest beef cow herd in the United States with over 2 million beef cows that calved in 2003 (NASS, 2003). In 1992, gross cash receipts from cattle in Missouri totaled $882 million which represented 40 percent of all livestock sales in the state (Lawrence and Otto, 2002). This industry relies on forage production as beef cattle derive approximately 83 percent of their feedstuffs from forages (Barnes and Taylor, 1985).

Pasture is typically the most economical source of nutrients for beef cattle (Henning, 2000) but the availability of forage from pasture fluctuates throughout the year. In the lower Midwest, the longest period of inadequate forage supply from pasture is from mid-December through mid-March (Matches and Burns, 1995).

A study in Texas showed that limit feeding an annual ryegrass (*Lolium multiflorum* Lam.) and small grain pasture in the winter is about $0.40 cheaper per cow per day than feeding hay and supplements (Texas Beef Industry, 2001). Livestock producers in the lower Midwest are looking for high quality forage for winter grazing (Kallenbach et al., 2003). Annual ryegrass and cereal rye (*Secale cereale* L.) are two forages that Missouri's beef producers are interested in to extend the grazing season for beef cattle.

Recent economic analyses show that extending the grazing season with annual ryegrass or cereal rye can reduce winter feed costs for beef cattle by more than 40% (Bishop-Hurley and Kallenbach, 2001). Beef producers are interested in annual ryegrass because it produces 2 to 3 tons of high-quality feed per acre before December and an additional 3 to 4 tons in the spring (Bishop-Hurley and Kallenbach, 2002). Winter cereal rye is also an option for extending the grazing season. It is the most winter hardy of the small grains, and it is also the most productive because of its quick growth in the autumn and spring (Samples and Sule, 1997).

Row-crop producers and producers with mixed row crop/livestock operations in the lower Midwest are also interested in annual ryegrass and cereal rye as a cover crop. Soybean [*Glycine max* (L.) Merr.] fields frequently remain fallow throughout winter, and producers are interested in annual ryegrass and cereal rye as a cover crop to reduce soil erosion and control winter annual weeds. Over winter, fallowed soybean fields become infested with winter annual weeds like common chickweed (*Stellaria media* L.), field pennycress (*Thlaspi arvense* L.), shepherd's-purse [*Capsella bursa-pastoris* (L.) Medic.], henbit [*Lamium amplexicaule* (L.)], and purple deadnettle [*Lamium purpureum* (L.) Lampu]. Many of these winter annual weeds have been shown to serve as hosts for problematic pests such as soybean cyst nematode (Venkatesh et al., 2000).

The establishment of annual ryegrass or cereal rye prior to or immediately after soybean harvest has three potential benefits. The three benefits are 1)to provide a winter forage source for Missouri's 2.2 million beef cows and 1.8 million stocker calves, 2)to suppress winter annual weeds, and 3)to reduce soil erosion. Although these possible advantages could increase the profitability of both beef and row-crop operations, little research has been done to examine all three of these prospective benefits at the same time in a cropping system in Missouri.

Although the potential is great to plant annual ryegrass or cereal rye as a winter crop on Missouri's 1.6 million hectares of soybean fields, there are still many questions that need to be answered. Perhaps two of the most important questions that producers want answered are 1) when should I plant annual ryegrass or cereal rye into soybean fields to maximize establishment and autumn growth? and 2) what is the effect of annual ryegrass or cereal rye on subsequent corn (*Zea Mays* L.) yields in a typical corn/soybean rotation)?

We hypothesized that beef cattle producers in Missouri could use overseeded cereal rye and annual ryegrass as a forage source in the autumn and early spring. Our objectives were to 1) determine how the seeding date impacts the establishment, growth, and forage production of annual ryegrass and cereal rye when planted into soybean fields, 2) determine how annual ryegrass and cereal rye seeding dates change winter annual weed populations in fallow soybean fields, 3)determine the percent residue cover of annual ryegrass and cereal rye, so one can predict a field's susceptibility to soil erosion, and 4)determine if adding annual ryegrass or cereal rye into a corn/soybean rotation impacts crop yield in the year following seeding.

Chapter 2

LITERATURE REVIEW

Annual Ryegrass. Annual ryegrass is an erect, cool season bunchgrass that has an extensive, fibrous root system (Sattell et al., 1998b). It is most productive in cool, moist climates with temperatures between 20 to 25°C. These characteristics allow annual ryegrass to grow well in the autumn and early spring in the lower Midwest (Hannaway et al., 1999).

About 90 percent of the 1.2 million hectares of annual ryegrass in the United States is used for winter pasture in the Southeast (Hannaway et al., 1999). The majority of annual ryegrass is overseeded into perennial warm season grasses such as bermudagrass [*Cynodon dactylon* (L.) Pers.] and bahiagrass (*Paspalum notatum* Flueggé) (Evers, 1995a; Hannaway et al., 1999). Annual ryegrass is also harvested for silage or hay or used as a nurse crop or cover crop in annual or perennial cropping systems (Sattel et al., 1998b).

Annual ryegrass is used widely in these regions as few other winter annual forages can provide as much pasture during autumn, winter and early spring. In a two year study of annual ryegrass cultivars, Redfearn et al. (2002) found that annual ryegrass cultivars yielded between 6,000 kg ha^{-1} and 12,000 kg ha^{-1} when harvested six times beginning in December. In Louisiana, Cuomo et al. (1999) found that annual ryegrass sown into tilled, warm-season annual grass residue produced between 6,520 kg ha^{-1} and 8,130 kg ha^{-1}.

In addition to its high yields, the nutritive value of annual ryegrass is high (Hannaway et al., 1999). In its vegetative stage, crude protein (CP) concentrations often exceed 200 g kg^{-1}, while acid detergent fiber and nuetral detergent fiber concentrations remain below 220 and 400 g kg^{-1}, respectively (Mooso et al., 1990; Lippke, 1995). These nutritive characteristics of annual ryegrass make for excellent animal performance (Lippke, 1995).

Many studies have investigated calf gains on annual ryegrass. Over a three year period in Arkansas, steers and heifers grazing dormant bermudagrass overseeded with annual ryegrass gained between 0.83 and 1.10 kg hd^{-1} day^{-1} (Coffey et al., 2002). A study done in northwestern Georgia found that crossbred steers grazing a mixture of annual ryegrass, cereal rye, and crimson clover (*Trifolium incarnatum* L.) gained 1.18 kg hd^{-1} day^{-1} (Hoveland et al., 1991). Other experiments with calves grazing annual ryegrass or an annual ryegrass mix pastures have shown similar results with gains between 0.62 kg hd^{-1} day^{-1} and 1.00 kg hd^{-1} day^{-1} (Arthington and Kalmbacher, 2003; Gunter et al., 2002; Mooso et al., 1990).

In addition to work with annual ryegrass as a forage crop, researchers have also studied annual ryegrass's use as a cover crop. Hively and Cox (2001) found that when interseeded into soybean, annual ryegrass provided 63 to 78% ground cover in the autumn and 76 to 83% ground cover in the spring. Additionally, annual ryegrass produced the most autumn biomass in both years of the experiment when compared to several legumes and cereal rye. In a cover crop study of annual ryegrass, black medic (*Medicago lupulina* L.), sudan grass (*Sorghum sudanense* L.), crimson clover, and a mix of cereal rye and Austrian winter pea (*Pisum sativum* L.) in Vancouver, weed weight was lowest by late winter in the annual ryegrass treatment, and the lowest weed species diversity also (Miles and Nicholson, 2003). Annual ryegrass can be used to accumulate residual N from the soil during the autumn and winter, thus reducing N losses caused when rains leach nitrate below the root zone. It has been used in bioremediation experiments as it is a heavy N feeder (Isse et al., 1999; Sattell et al., 1998b). Finally, annual ryegrass cover crops can suppress weeds by competing for light, water, and nutrients (Barnes and Putnam, 1983). This leads to the potential for decreasing pesticide use and environmental pollution (Abdin et al., 1998).

Annual ryegrass is also well suited to soil conservation uses (Malik et al., 2000; Hannaway, 1999). Annual ryegrass has a dense, shallow, fibrous root system (Ridley and Simpson, 1994). This root system allows annual ryegrass to protect soil aggregate breakdown during the winter and results in better soil structure after spring tillage when compared to fallow fields (Hermawan and Bomke, 1997).

Annual ryegrass has some disadvantages as a cover crop. In central New York, Hively and Cox (2001) found that annual ryegrass was susceptible to winter kill. In Vancouver, Miles and Nicholson (2003) observed that annual ryegrass came back as weed the year after it was grown as a cover crop and was hard to control. When corn followed annual ryegrass in southwestern Ontario, aboveground corn biomass N at anthesis was 25.6 kg ha^{-1} less than when no cover crop was grown. In the same experiment, corn yields were 1.22 to 2.36 Mg ha^{-1} lower when it was planted after an annual ryegrass cover crop in two out of three years when compared to treatments with no cover crop (Vyn et al., 1999).

Cereal Rye. Cereal rye is an erect annual grass with greenish blue, flat blades and an extensive fibrous root system (Sattell et al., 1998a). Cereal rye is extremely winter hardy, grows late into the autumn, and is quite tolerant of drought (Nafziger, 2000b; Sattell et al., 1998a). Cereal rye can grow on infertile soils where other cereal grains would normally fail (Sattell et al., 1998a).

Cereal rye is a widely adapted, highly versatile forage used for pasture, green chop, silage, hay and as a cover crop (Sattell et al., 1998a; Fohner, 2002). The National Agricultural Statistics Service (2002) reported that in 2002, 56 million hectares of cereal rye were planted, but only 11 million hectares were harvested for grain.

Small grains like cereal rye are excellent crops for grazing, particularly prior to reproductive growth (Fohner, 2002). In a cereal rye and annual ryegrass stockpile experiment in Missouri, cereal rye did not exhibit freeze damage under colder temperatures, but annual ryegrass did (Kallenbach et al., 2003). Cereal rye also fits into year-round grazing systems because of its early season production (Moyer and Coffey, 2000).

Another positive of cereal rye is that it has the highest season-long forage production of the cereal grains including triticale, wheat, and barley (Watson et al., 1993). In Kansas, Moyer and Coffey (2000) found that cereal rye grown as a monoculture produced more early-season forage than either wheat or barley. They also found that when the cereal rye was no-tilled into bermudagrass, it produced similar or greater early yield than that of the other cereal grains tested. In one year of a stockpile study in Missouri, Kallenbach et al. (2003) found that cereal rye always produced the most forage when compared to two annual ryegrass cultivars. In the other year of the study, cereal rye had lower yields from December through February than annual ryegrass. However, the cereal rye constantly accumulated more forage than annual ryegrass between January and March, which led to greater yields in late winter.

When vegetative, the nutritive value of cereal rye is high. In Ohio, Samples and Sules (1997) found crude protein levels were as high as 340 g kg^{-1}, acid detergent fiber values were as low as 170 g kg^{-1}, and neutral detergent fiber values as low as 208 g kg^{-1} in cereal rye. In Kansas, Moyer and Coffey (2000) reported crude protein levels as high as 176 g kg^{-1} in cereal rye interseeded into bermudagrass and as high as 257 g kg^{-1} when grown in monoculture.

Due to its desirable forage qualities, several studies have investigated cattle rates of gain on cereal rye and cereal rye mixed pastures. In Arkansas, steers and heifers backgrounded on a mixture of cereal rye and annual ryegrass sod-seeded into dormant bermudagrass gained 0.82 to 1.00 kg day^{-1} (Coffey et al., 2002). In Ontario, Canada, steer and heifer calves averaged 0.68 kg hd^{-1} day^{-1} on cereal rye over a 28 day period beginning on September 20, 2000 (Johnston, et al., undated). Other studies have shown calf gains between 0.77 kg day^{-1} and 1.1 kg day^{-1} (Gunter et al., 2002; Samples and Sules 1997).

Although cereal rye offers many positive attributes for grazing, it does have some disadvantages. Researchers in Arkansas found that pastures of cereal rye and wheat matured early in the grazing season (early April). Subsequently, the grazing cows on small grain pastures had a lower body condition score in May than cows fed hay and supplemented with corn gluten (Gunter et al., 2002). Cereal rye declines in quality because it begins reproductive growth and becomes unpalatable earlier in the spring than other cereals (Watson et al., 1993). In Ontario, Canada, calf gain per hectare from cereal rye pasture was less than half of that from annual ryegrass (73 to 157 kg ha^{-1} (Johnston et al., undated).

In addition to the research on the forage aspects of cereal rye, much research has been done on its use as a cover crop. Cereal rye grown as a cover crop offers the advantages of low seed cost and fast establishment of ground cover in the autumn (Nafziger, 2000a). Cereal rye is also effective as a cover crop for scavenging residual N from the soil in the winter and in the early growing season (Nafziger, 2000a; Rasse et al., 2000; Upendra et al., 1998). Additionally, cereal rye is frequently used to stop wind erosion of sandy soils (Nafziger, 2000b). Kessavalou and Walters (1997) found that cereal rye proved to be a suitable cover crop when planted into soybean stubble. They found that it produced an average of 1.4 Mg ha^{-1} of dry matter and that was sufficient to provide a persistent surface cover for erosion protection comparable to that of corn residue. Furthermore, cereal rye as a cover crop can also help control winter annual weeds. Mowing cereal rye leaves heavy mulch that suppresses weeds, thus reducing herbicide needs (Becker, 1995). Shrestha et al. (2002) found that soybean planted into a cereal rye cover crop had lower weed densities than plots without cover crops.

Using cereal rye as a cover crop can have some disadvantages. Research done in Iowa showed that cereal rye grown as a cover crop before corn reduced grain yield by an average of 1.6 Mg ha^{-1} (Johnson et al., 1998). Similarly, Tollenaar et al. (1993) and Raimbault et al. (1990) observed that cereal rye preceding corn in Ontario delayed maturity and/or lowered grain yields. They stated that the delays in development and lower yields may be caused by the amount of cover crop biomass produced, nitrogen deficiency, and/or allelopathic effects. In Nebraska, Kessavalou and Walters (1997) only experienced lower corn yields in one of three years. They determined that the lower yield in the one year was caused by the allelopathic phytoxicity of rye residues. Raimbault et al. (1990) suggested that killing the cereal rye 2- to 3-weeks before planting corn may eliminate the alleopathic effect of cereal rye on the subsequent corn crop.

Chapter 3

MATERIALS AND METHODS

Overseeding annual ryegrass and cereal rye into standing soybean was studied at Bradford Research and Extension Center, near Columbia, MO (38°57’N 92°20’W). The soil type at this location is a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs). Two “cycles” of this experiment were conducted on different sites each year with each cycle taking approximately 18 months and is described later. The first “cycle” went from May of 2003 to November of 2004, and the second cycle went from the May of 2004 to November of 2005. Hereafter, first cycle will be referred to as Year 1, and the second cycle will be referred to as Year 2.

Roundup Ready ‘Pioneer 92B75’ (maturity group 2.7) soybean was planted on 24 May in Year 1 and on 17 May in Year 2. The field was chisel plowed in the autumn preceding planting and disked in the spring prior to planting. Glyphosate was used to control weeds during the growing season. Soybean was drilled in 20 cm wide rows at 430,000 seeds ha^{-1}. Soil P and K was maintained at the levels recommended by the University of Missouri Soil Testing Laboratory.

This experiment had seven treatments, consisting of three different seeding dates for both annual ryegrass and cereal rye into soybean and an unseeded control. The 7 treatments are shown in Table 1. At the stages and dates listed in Table 1, either ‘Saddle Pro’ annual ryegrass or ‘Wintergrazer 70’ cereal rye was overseeded into soybean. The seeding rate for the annual ryegrass was 39 kg ha^{-1} of pure live seed, and for the cereal rye it was 140 kg ha^{-1} of pure live seed. The annual ryegrass and cereal rye was overseeded with a drop type seeder that had seed openings on 13 cm centers. The drop seeder was modified with 1.5 m diameter tires (Fig. 3) that provided 0.75 m of ground clearance, which was sufficient to clear the soybean.

Soybean yield was measured in all seven treatments by direct combining three 1.5 m x 10.6 m strips from each plot the same year that the annual ryegrass and cereal rye were overseeded. In Year 1, soybean was harvested on 17 and 18 September and in Year 2 soybean was harvested on 13 September. Sub-samples from each plot were retained for test weight and moisture determination. After soybean harvest, 67 kg ha^{-1} of N as ammonia nitrate was broadcast to stimulate annual ryegrass and cereal rye growth. In early March, an additional 67 kg ha^{-1} of N was applied to maximize spring growth. Nitrogen was not applied to the control plots as it would not normally be applied to a fallow soybean field.

The tiller density of the annual ryegrass and the cereal rye was determined on 16 October and 14 April of Year 1 and on 15 October and 15 April of Year 2. Tiller density was measured by counting the tillers taken from ten, 5 cm diameter cores from each plot.

Winter annual weed suppression was measured by visually rating plots for percent weed cover on 9 October of Year 1 and 15 October Year 2 following annual ryegrass and cereal rye establishment. Additionally, plots were also visually rated for percent weed cover on 17 March of Year 1 and 14 March of Year 2. Also in March of each year, weed density was determined by counting the weeds in three 0.1 m^2 quadrats randomly placed in each plot.

Forage growth from overseeded plots was evaluated weekly by taking 20 readings with a rising plate meter (Rayburn and Rayburn, 1998). When the average of the five replications for a treatment reached 15 rising plate meter units, forage from that treatment was harvested as described below. Annual ryegrass and cereal rye were 20 to 25 cm tall when 15 rising plate meter units were obtained. Once a treatment reached 15 rising plate meter units, forage yield was determined by clipping three 1.3 m x 7.6 m strips in each plot. All forage was harvested using a Hege 212 forage harvester (Wintersteiger, Germany) set to leave a 7.6 cm stubble. The harvest dates are listed in Table 2. The combined fresh mass of the three strips in each plot was recorded. A 350 g(±50g) sub-sample from each plot was dried at 50°C for at least 96 h in a forced air oven to determine dry matter. Forage quantity was evaluated in the autumn, spring, and is also presented collectively. After the samples were dried, the forage was ground to pass through a 1-mm screen using an Udy (Udy Corporation, Fort Collins, CO) cyclone mill.

Forage quality was examined by autumn, spring and annual average crude protein and acid and neutral detergent fiber, and weighted according to the quantity harvested during each period. Crude protein, acid detergent fiber, and neutral detergent fiber were measured from ground samples using near infrared reflectance spectroscopy (NIRS) using the scanning, calibration, and validation methods described by Marten et al. (1989) (Table 3). Crude protein for calibration samples was determined by measuring total N content using a LECO FP-428 (LECO Corp., St. Joseph, MI) and then multiplying N values by 6.25. Acid detergent fiber and neutral detergent fiber for calibration samples were determined using the methods described by Van Soest and Robertson (1980).

Root mass of the annual ryegrass and cereal rye was measured from all plots, except the unseeded control plots on 28 April of Year 1 and 27 April of Year 2, just prior to planting the corn. Root mass for the annual ryegrass and cereal rye were determined by randomly taking ten 2.54 cm cores in each plot, except control plots, to a 45 cm depth and split into 0-2, 2-15, 15-30, and 30-45 cm divisions. These sampling depths encompass more than 90% of the roots of annual ryegrass (Sheng and Hunt, 1991) and cereal rye (Ridley and Simpson, 1994). Three of the ten cores in each plot were taken to a depth of 100 cm to examine root growth below 45 cm.

All soil cores were dried before washing. Roots were separated from the soil with a hydropneumatic elutriation root washer (Smucker et al., 1982). The roots were dried at 75°C to constant weight, and weighed to determine differences in root mass (Sheng and Hunt, 1991).

Soil organic matter and nutrient levels were determined for each plot in the spring of each year on 29 April of Year 1 and 27 April of Year 2, just prior to corn planting. Ten cores were randomly taken in each plot. The cores were 2 cm in diameter and were taken to a depth of 15 cm. Samples were evaluated for pH, neutralizable acidity, organic matter, Bray I P, Calcium, Magnesium, Potassium, and cation exchange capacity by University of Missouri Soil Testing Laboratory

Corn the subsequent year. The following spring, the annual ryegrass and cereal rye were terminated on 27 April of Year 1 and Year 2 with 1.5 kg ai ha^{-1} of glyphosate. This was followed by a 2 week fallow period to eliminate allelopathic effects of cereal rye on subsequent corn yields (Raimbault et al., 1990). After this, ‘Pioneer 33P67’ corn was no-tilled into plots with a 6-row corn planter to measure residual effects. The corn hybrid was planted on 76 cm rows at 72,000 seeds ha^{-1}. In Year 2, the annual ryegrass was not sufficiently terminated with the glyphosate, so all plots were sprayed with an additional 2.2 kg ha^{-1} of atrazine, 27 g ha^{-1} of nicosulfuron, and 13 g ha^{-1} of rimsulfuron.

In Year 1, due to poor stands caused by soil crusting, the corn was replanted on 2 June. Three weeks after planting, plant populations were determined in each plot by counting the plants in five random 5.3 m strips in each plot. One hundred eighty kg ha^{-1} of N was applied to the corn each year. Other soil fertility and weed and insect control applications followed the management practices recommended for corn by the University of Missouri.

Directly after planting corn, surface residue cover was estimated using a 100-point line-transect (Shelton et al., 1993). Five counts were taken in each plot with a 20-point line-transect and the cumulative residue count was expressed as a percentage (Kessavalou and Walters, 1997).

To determine how annual ryegrass and cereal rye influence the root mass of subsequent crops, the root mass of the following corn crop was measured just after silking (reproductive stage 1 or R1). After stage R1, corn root depth has been shown to be constant (Bauder et al., 2003). Nearly 95% of corn roots occur in the top 90 cm of soil (Bauder et al., 2003), so the cores were taken to a 100 cm depth. On 13 August of Year 1, three cores were taken randomly in the row and 3 cores were taken randomly in between the rows in each plot (Sheng and Hunt, 1991). The cores were split into 0-2, 2-15, 15-30, 30-45, and 45-100 cm divisions. Roots were washed using the same procedures as previously described.

On 12 November of Year 1, corn yield was measured in all treatments the year following the annual ryegrass and cereal rye seeding. Four 0.8 m x 4.5 m rows were harvested from each plot by hand. The corn was shelled using a stationary thresher. Sub-samples from each plot were retained for moisture determination.

Statistical Analysis. The seven treatments were replicated five times in a completely randomized design {35 total plots (5 replications x 7 treatments)}(Fig. 1 and Fig. 2). Individual plots were 10.6 m x 9.1 m. Analysis of variance was conducted on main effects and all possible interactions using the outline by Steel and Torrie (1980). Statistical Analysis Systems (SAS) software (version 8.2) was used to analyze the data (SAS Institute Inc., 1999). All interactions on main effects and all possible interactions were considered significant when $P<0.05$.

Chapter 4

RESULTS AND DISCUSSION

Soybean Yield. Soybean yield was not affected by any of the overseeding treatments in either year (Table 5). It appears that annual ryegrass or cereal rye seedlings did not compete with soybean for nutrients or water in a significant way. Soybean yield was lower in Year 1, due to a mid-season drought (Table 4) which limited soybean yield to an average of 1,075 kg ha^{-1} (Table 5). In Year 2, abundant summer rains (Table 4) led to a 75% increase in soybean yield (average of 4,300 kg ha^{-1}) (Table 5). These results were similar to those of Hively and Cox (2001) who also found that overseeded annual ryegrass and cereal rye did not affect soybean yield. Our research shows that overseeding can be done at the R 5.5 stage or later without affecting soybean yield or interfering with soybean harvest.

Tiller density. In autumn of Year 1, the annual ryegrass overseeded at R 6.5 had 43% more tillers than the other two annual ryegrass treatments (Table 6). Weather conditions immediately following overseeding are most likely the reason for the differences. In Year 1, the annual ryegrass overseeded at R6.5 received 6 mm of rain the day before overseeding, and the wetter conditions likely caused a greater percentage of it to germinate and thus produce more tillers in autumn than the treatment overseeded at R 5.5. Moreover, the R 6.5 treatment was overseeded 14 days before the R 8 treatment, which allowed it more time to produce a higher tiller density. In the autumn of Year 2, the annual ryegrass overseeded at R 8, had 48% higher tiller density than the annual ryegrass overseeded at R 5.5 (Table 6). It was more than 12 days before the annual ryegrass that was overseeded at R 5.5 received any rain, while the other two treatments received at least 16 mm of rainfall less than 2 days after overseeding. The moisture differences at time of germination likely caused the differences in tiller density. By spring, of either year, the tiller density of annual ryegrass was not different in any treatment (Table 6). Venuto et al. (2003) found that annual ryegrass tillers per plant decreased as plant numbers increased. This helps to explain how tiller density among annual ryegrass treatments became insignificant by spring of each year. For the annual ryegrass, the treatment overseeded at R 6.5 consistently had a tiller density that was the highest or not significantly less than the treatment that had the highest tiller density. From our observations, it seemed that the soybean leaf drop that occurred at R 6.5 helped the annual ryegrass overseeded then have a higher germination rate. Overseeding date did not affect the number of cereal rye tillers produced in the autumn or spring of either year although there were 25% more cereal rye tillers than in the spring of Year 2 (Table 6) than in spring of Year 1. In March of Year 1, average temperatures were slightly warmer than in March of Year 2 (Table 4) and are likely the cause for the year main effect. It appears that cereal rye consistently established regardless of timing of overseeding.

Forage Yield. Forage yield was divided into three divisions: autumn, spring, and total yield (Fig. 4). In autumn of Year 1, annual ryegrass overseeded at R 6.5 and cereal rye overseeded at R 5.5 yielded the most autumn forage averaging 1485 kg ha^{-1}. Cereal rye overseeded at R 8 yielded the least autumn forage as it never reached the 15 rising plate meter units (20 to 25 cm height) needed to trigger a forage harvest. In autumn of Year 2, the annual ryegrass overseeded at R 6.5 yielded 1,870 kg ha^{-1} which was 23 to 62% more than the other treatments. The lowest yielding treatments in autumn of Year 2 were the cereal rye overseeded at R 5.5 and R 6.5 which averaged only 866 kg ha^{-1}. While there were some variations among high and low yielding treatments between years, annual ryegrass overseeded at R 6.5 produced consistently high autumn yields. While our high producing treatment yielded slightly less than those reported by Kallenbach et al. (2003), their seeding method was into a prepared seedbed, so it is not that surprising that in an overseeding scenario that our autumn forage yields were less. Work by Evers (1995b) found that overseeding annual ryegrass into existing bermudagrass sods gave lower autumn forage yields than when planted into a prepared seedbed. Overseeding annual ryegrass into soybean seems to give a similar response.

In spring, cereal rye began to grow earlier and thus, tended to produce more spring yield than annual ryegrass. Cereal rye's spring forage production was similar each year, with all the treatments yielding approximately 2,800 kg ha^{-1}. Annual ryegrass overseeded at R 5.5 and R 6.5 yielded equal or less (average of 2,227 kg ha^{-1}) than any of the cereal rye treatments, and annual ryegrass overseeded at R 8 always yielded the least (average of 1,910 kg ha-1). The cereal rye yields from our experiment in the spring are similar to the results reported by Moyer and Coffey (2000), and both the annual ryegrass and cereal rye yields are similar to those of Kallenbach et al. (2003) in year 2 of their study.

While variations existed among total forage for treatments, the annual ryegrass and cereal rye overseeded at R 6.5 always was in the highest group. For total yield in Year 1, annual ryegrass overseeded at R 6.5 and cereal rye overseeded at R 5.5 and R 6.5 averaged 3,817 kg ha^{-1}, which was 33% more than the lowest yielding treatment of annual ryegrass overseeded at R 8. For the Year 2 total yield, the annual ryegrass overseeded at R 5.5 and R 6.5 and the cereal rye overseeded at R 6.5 yielded the most total forage (average of 3,916 kg ha^{-1}). Annual ryegrass overseeded at R 6.5 yielded (4,130 kg ha^{-1}) at least 13% more total forage than the annual ryegrass overseeded at R 8 and the cereal rye overseeded at R 5.5 and R 8.

From the data we gathered, the R 6.5 stage is the best time to overseed both annual ryegrass and cereal rye into soybean as this timing consistently gave the highest total forage yields. Other treatments yielded the same amount in some years, but not in both years. Additionally, the annual ryegrass overseeded at R 6.5 consistently yielded the most autumn forage from year to year. Annual ryegrass overseeded at R 6.5 would be best for winter-feeding as it offers the highest autumn yields, which would allow more days of grazing in late autumn or it could be stockpiled and grazed later in the winter (Kallenbach et al., 2003). The cereal rye overseeded at R 6.5 consistently yielded the most spring forage. It offers the benefit of the most forage available early in the spring which is an important feature for year-around grazing systems (Blaser, 1986).

Forage Quality. Crude protein, acid detergent fiber, and neutral detergent fiber of annual ryegrass and cereal rye during Year 1 and Year 2 are presented for autumn, spring, and annual averages. These averages were weighted according to the quantity harvested during each period. Crude protein concentrations were approximately 108 g kg^{-1} higher in autumn than spring and, with one exception, crude protein concentrations were equal within a season for all treatments both years (Table 7). The one exception was in autumn of Year 1, when cereal rye overseeded at R 6.5, had a crude protein concentration of 313 g kg^{-1}, which was 10% higher than any other treatment. Annual average crude protein, however, did show differences between treatments in both years.

In Year 1, annual average crude protein concentration for annual ryegrass overseeded at R 6.5 was 10% higher than annual ryegrass overseeded at R 5.5 and R 8. Crude protein concentrations were lowest for cereal rye overseeded at R 8. This treatment had no appreciable autumn growth and thus its forage quality was only measured from the lower quality spring growth. In Year 2, the annual ryegrass treatments as well as cereal rye overseeded at R 5.5 had the greatest crude protein levels. All treatments had crude protein levels above 210 g kg^{-1} which is more than sufficient for nearly any class of beef or dairy cattle (National Research Council, 1996, 2001). The annual ryegrass treatments were often higher in annual average crude protein than the cereal rye treatments. This was caused by the combination of high cereal rye dry matter yields in the spring and lower crude protein levels in the spring.

Acid detergent fiber was equal for all treatments in the autumn of both years (Table 8) but overall it was lower in autumn of Year 1 (average of 184 g kg^{-1}) than autumn Year 2 (average of 207 g kg^{-1}). In spring, acid detergent fiber values for all treatments increased compared to autumn but annual ryegrass increased less than cereal rye. In the spring of both years the annual ryegrass treatments were approximately 60 g kg^{-1} lower in acid detergent fiber than the cereal rye treatments. The annual average acid detergent fiber values followed the same trend with annual ryegrass treatments being 24% lower in Year 1 and 19% lower in Year 2 than cereal rye treatments, respectively. Neutral detergent fiber was fairly consistent between autumn, spring and annual average for both years with an average value of 550 g kg^{-1}. While values for individual treatments were sometimes different statistically, the differences would not be expected to be contrasting biologically or in terms of expected animal performance (National Research Council, 1996, 2001) (Table 9).

Our forage quality values are similar to those reported by Kallenbach et al. (2003). Furthermore, our crude protein and neutral detergent fiber levels were comparable to those found by Redfearn et al. (2002) in Oklahoma. Overall, the forage quality samples show that annual ryegrass and cereal rye are excellent quality feeds, although the quality of annual ryegrass usually equals or surpasses cereal rye. The high crude protein and low acid and neutral detergent fiber values throughout the season show that both of these forages rival early bloom alfalfa in crude protein and corn silage in energy. However, cereal rye matures earlier in the spring than annual ryegrass, and this suggests that its use as high quality forage after April is limited in Missouri. Annual ryegrass's low acid detergent fiber values and high crude protein values would be sufficient to support beef calves gaining 1.0 or more kg d^{-1} or lactating dairy cows (National Research Council, 1996, 2001) and its comparatively long window of use makes it simpler for producers to manage. In short, few other forages can produce such excellent quality feed for winter and early spring grazing.

Percent Weed Cover and Spring Weed Counts. Weed cover in autumn of Year 1 (average of 17%) was about 2.5 times greater that in autumn of Year 2, but little meaningful differences existed between treatments in either year. Weed cover remained low for all the overseeded treatments in spring but in the unseeded control plots weed cover increased dramatically. In spring of Year 1, all the overseeded treatments had at least 65% less weed cover than the control plots (Table 10). Similarly, in the spring of Year 2, the overseeded treatments had a least 89% less weed cover than the control treatment. Spring weed counts supported our visual ratings as weed counts in the spring of Year 1 and Year 2 showed similar trends (Table 11). Our results were in agreement with Shrestha et al. (2002) who found that weed densities were less in plots with cover crops such as cereal rye than with plots without cover crops. It is clear that seeding annual ryegrass or cereal rye into soybean fields reduces the prevalence of winter annual weeds.

Roots. With one exception, the root mass of annual ryegrass and cereal rye was equal for all treatments (Tables 12 and 13). The one exception was in the 0-2 cm division in Year 1, where annual ryegrass produced at least 56% more root mass than cereal rye for comparable seeding dates. However, date of overseeding had no influence on root mass of either annual ryegrass or cereal rye in either year. Additionally, more than 96% of annual ryegrass and cereal rye root mass was concentrated in the upper 15 cm of the soil profile. Our results agreed with those of Sheng and Hunt (1991) and Ridley and Simpson (1994) who found that annual ryegrass and cereal rye roots were concentrated in upper soil layers.

Following a similar trend, corn root mass was equal for all treatments (Table 14). The data shows that the growing annual ryegrass or cereal rye in the autumn and spring prior to a corn crop does not significantly affect the mass of corn roots. We had hypothesized that the root residue present from where the annual ryegrass and cereal rye had been overseeded could lead to increased soil tilth and thus corn root growth. While our data did not show this, our study was conducted for only one year at each site. The residual root mass from a cover crop grown on the same site for a period of years might show a different result.

Percent Residue Cover. In the spring, all annual ryegrass and cereal rye treatments had at least 62% more residue cover than the control treatment (Table 15). Comparisons among overseeding treatments gave inconsistent trends. Treatments ranged from 52 to 68% residue cover and while at times there were some significant differences between treatments, it is doubtful that these differences represent any biological significance in terms of soil erosion or runoff potential. However, the control treatment may have an erosion potential 1.7 times greater than any of the overseeded treatments (Dickey et al., 1986). The residue cover results were lower than those found by Kessavalou and Walters (1997), but this was expected as their treatments were not harvested for forage. Nonetheless, there was still significantly more residue cover than the control, and this would help prevent soil erosion.

Corn. Corn population did not very significantly by treatment or year, but corn population did have a treatment x year interaction. In the spring of Year 1, corn population averaged 59,590 plants ha^{-1} and in the spring of Year 2 corn populations averaged 59,033 plants ha^{-1} (Table 16). Some of the interactions present could be do to the annual ryegrass overseeded at R 6.5 having the lowest plant populations in Year 1, and the following year that treatment had the highest plant populations. From our data, no-tilling corn after annual ryegrass or cereal rye does not affect the corn population. This allows a producer to use overseeded annual ryegrass and cereal rye without concern that it would affect the subsequent corn crop's population.

In Year 1, the corn yield averaged 8,801 kg ha^{-1} (Table 17), and there were no significant differences between treatments. Since there were no yield differences between the treatments, annual ryegrass and cereal rye can be grown to provide forage without affecting subsequent corn production. These results are similar to those of Hively and Cox (2001) who found that a cereal rye cover crop did not affect the following corn crop when compared to the control treatment. In one out of two years, they did find that corn following annual ryegrass yielded significantly less than the control treatment. Our results were different than Vyn et al. (1999) and Kessavalou and Walters (1997) who found that annual ryegrass and cereal rye cover crops often negatively affected corn yield. Kessavalou and Walters (1997) and Raimbault et al. (1990) cited cereal rye residue allelopathic properties as the possible cause for the decrease in yield. Our plot had only a 7.6 cm stubble left on them, so this coupled with waiting to plant the corn two weeks after terminating the annual ryegrass and cereal rye may have caused the allelopathic effect to be insignificant. From our results, producers could plant corn after annual ryegrass or cereal rye used for forage without decreasing yields.

Chapter 5

CONCLUSIONS

These results demonstrate that livestock operations in the lower Midwest could use annual ryegrass and cereal rye overseeded into soybean for winter grazing. All treatments yielded over 2,500 kg ha^{-1} for the season (with a high of 4,200 kg ha^{-1}), which would supply much needed pasture for winter grazing. While all treatments were adequate forage sources, overseeding at the R 6.5 stage consistently produced the most forage for both annual ryegrass and cereal rye. Other treatments yielded the same amount in some years, but not in both years. Additionally, the annual ryegrass overseeded at R 6.5 consistently yielded the most autumn forage from year to year. It would appear to be the best treatment for winter-feeding as it offers the most dry matter available and could be grazed late into the autumn. Conversely, the cereal rye overseeded at R 6.5 consistently yielded the most spring forage. It offers the benefit of the most dry matter available early in the spring. The high quality of these forages makes them excellent feed for nearly all classes of livestock including stocker calves and lactating dairy cows. Our data also indicates that overseeding annual ryegrass reduces winter annual weeds and improves soil conservation by providing residue cover. In the autumn the annual ryegrass and cereal rye were overseeded, soybean yield was unaffected. Similarly, in the year following overseeding, corn yield was unchanged on plots that had annual ryegrass and cereal rye grown on them. One may note that terminating the annual ryegrass in the spring of Year 2 took an additional spraying. The cereal rye was much easier to kill because it was close to physiological maturity at the time of termination.

From a research stand point, the next step would be to incorporate the best treatments into a grazing study with beef cows or stocker calves. Also, considering the work of Venuto et al. (2003) higher autumn seeding rates may be tried to increase autumn forage yields. Another possible idea could be to try planting soybean for the subsequent crop instead of corn, so more of the annual ryegrass' growing season could be utilized.

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Figure 1. Plot map of overseeding treatments in Year 1 at the Bradford Research and Extension Center near Columbia, MO. Year 1 was for the 2003-2004 cycle.

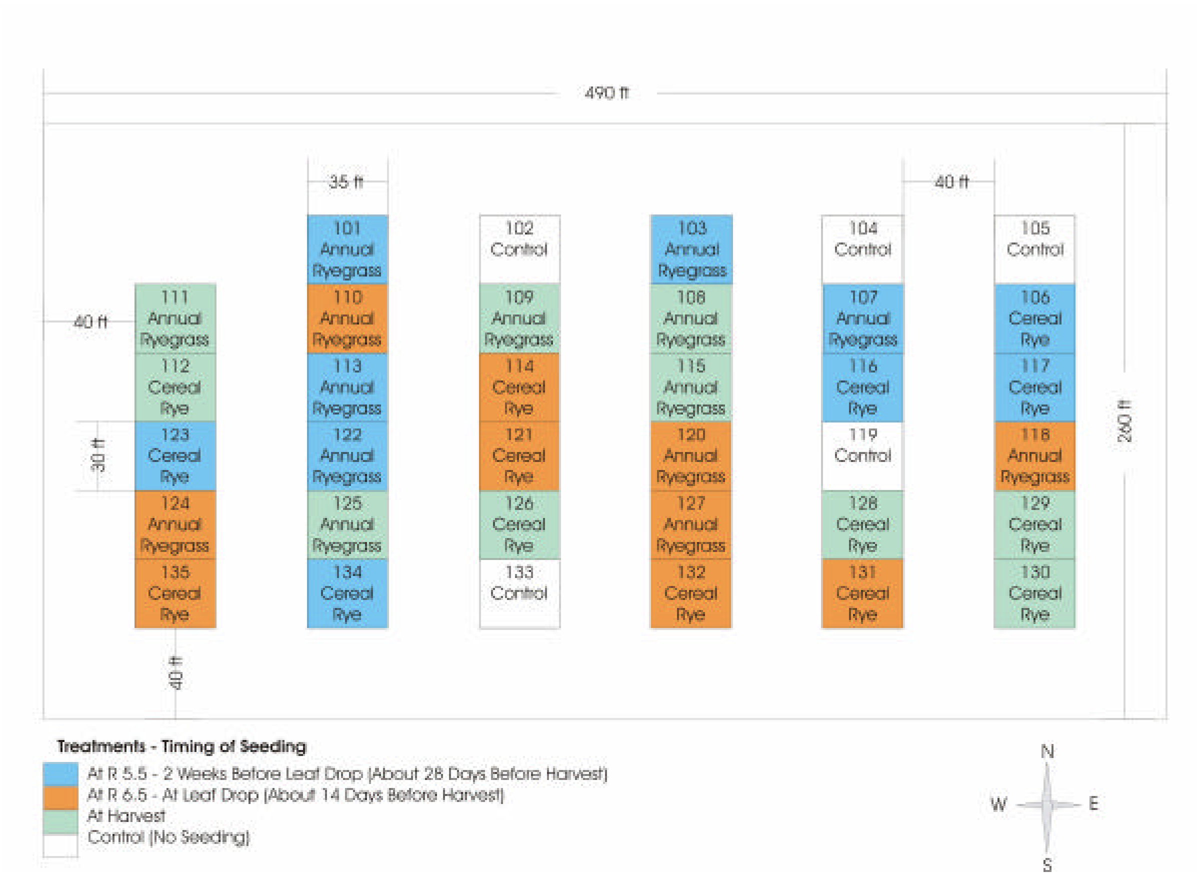

Figure 2. Plot map of overseeding treatments in Year 2 at the Bradford Research and Extension Center near Columbia, MO. Year 2 was for the 2004-2005 cycle.

Figure 3. Modified drop seeder used for overseeding annual ryegrass and cereal rye into soybean.

Figure 4. Forage yield of annual ryegrass and cereal rye overseeded into soybean. Data is from the autumn and spring of Year 1 and Year 2. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle. Lower case letters inside bars are for autumn and spring yield and capital letters on top of bars are for total forage yield in each year for a given treatment.

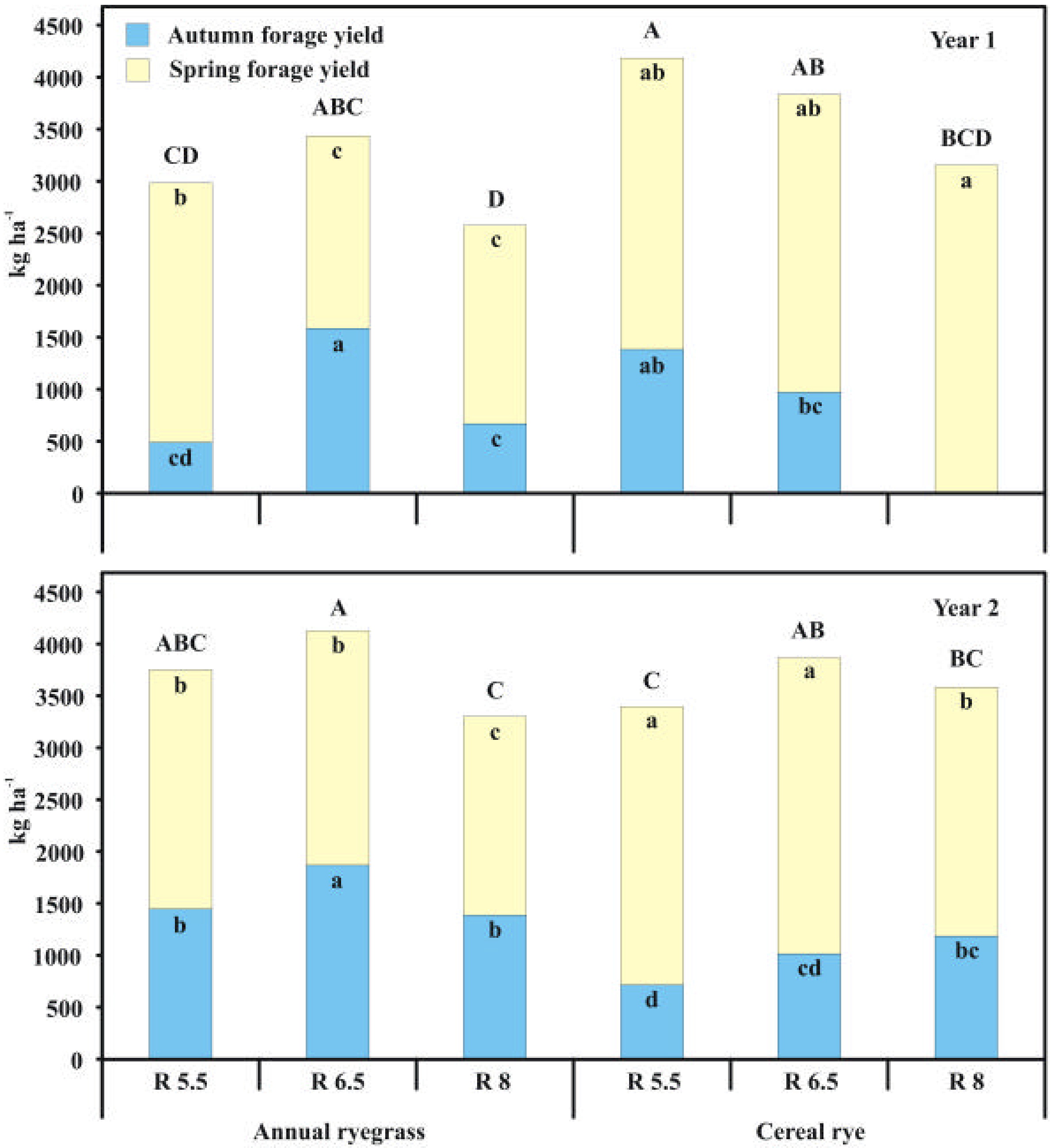

Table 1. Annual ryegrass and cereal rye overseeding treatments based on soybean developmental stage and Year 1 and Year 2 overseeding dates. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Description of Treatment	Year 1 Seeding Dates	Year 2 Seeding Dates
Annual ryegrass	R5.5	2 weeks before leaf drop	18 August	5 August
Cereal rye	R5.5	2 weeks before leaf drop	18 August	5 August
Annual ryegrass	R6.5	At leaf drop	4 September	19 August
Cereal rye	R6.5	At leaf drop	4 September	19 August
Annual ryegrass	R8	At harvest	18 September	13 September
Cereal rye	R8	At harvest	18 September	13 September
Control	-	-	-	-

Table 2. Harvest dates for Year 1 and Year 2 of annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle. Forage was harvested when an individual treatment averaged 15 rising plate meter units (20-25 cm in heights).

Species	Reproductive Stage of Soybean	Year 1 Harvest Dates	Year 2 Harvest Dates
Annual ryegrass	R5.5	30 October, 5 April, 19 April, 26 April	25 October, 8 November, 15 April, 25 April
Cereal rye	R5.5	24 October, 2 April, 14 April, 26 April	25 October, 1 April, 15 April, 25 April
Annual ryegrass	R6.5	30 October, 24 November, 5 April, 19 April, 26 April	25 October, 8 November, 15 April, 25 April
Cereal rye	R6.5	24 October, 2 April, 14 April, 26 April	25 October, 1 April, 15 April, 25 April
Annual ryegrass	R8	17 November, 5 April, 19 April, 26 April	8 November, 15 April, 25 April
Cereal rye	R8	2 April, 14 April, 26 April	8 November, 1 April, 15 April, 25 April

Table 3. Near-infrared reflectance spectroscopy calibration and validation statistics for crude protein, acid detergent fiber, and neutral detergent fiber.

Constituent	n	Mean	SEC†	SECV‡	R^2§	1-VR¶
		g kg^{-1}				
Crude Protein	129	187	9.039	10.848	0.9777	0.9678
Acid detergent fiber	128	286	21.292	29.726	0.9493	0.901
Neutral detergent fiber	131	469	19.601	28.74	0.9718	0.9396

† SEC = standard error of calibration.
‡ SECV = standard error of cross-validation in modified partial least squares regression.
§ R^2 = Coefficient of determination for calibration.
¶ 1-VR = 1 minus the variance ratio calculated in cross-validation during modified partial least squares regression.

Table 4. Monthly total precipitation and average air temperature at Columbia, MO during Year 1 and Year 2. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle. Historic averages represent 36 years of data.

	Monthly Total Precipitation			Average Temperature		
	Year 1	Year 2	Historic Average	Year 1	Year 2	Historic Average
Month	mm			°C		
May	137	120	127	17	19	18
June	167	42	110	21	21	22
July	42	112	93	25	23	25
August	71	130	83	26	21	24
September	241	24	98	18	20	20
October	58	78	82	14	14	14
November	68	123	74	8	8	7
December	75	23	63	2	2	0
January	42	131	37	-4	-1	-3
February	13	49	47	0	4	0
March	151	23	80	8	6	7
April	65	110	97	14	14	13

Table 5. Soybean yield for Year 1 and Year 2 with annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Year 1	Year 2
		kg ha^{-1}	
Annual ryegrass	R5.5	1,142	4,300
Cereal rye	R5.5	1,008	4,502
Annual ryegrass	R6.5	1,142	4,300
Cereal rye	R6.5	941	4,233
Annual ryegrass	R8	1,142	4,233
Cereal rye	R8	1,209	4,166
Control	-	1,008	4,367
LSD (0.05)	-	NS	NS

Table 6. Tiller density in the autumn of Year 1 and Year 2 and in the spring of Year 1 and Year 2 for annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Autumn Year 1	Autumn Year 2	Spring Year 1	Spring Year 2
		tillers m^{-2}			
Annual ryegrass	R5.5	3,779	4,055	5,683	6,315
Annual ryegrass	R6.5	6,542	6,453	6,078	4,578
Annual ryegrass	R8	3,730	7,933	5,900	6,512
LSD (0.05)	-	1,737	2,569	NS	NS
Cereal rye	R5.5	3,888	3,897	5,831	4,243
Cereal rye	R6.5	3,799	4,716	6,078	5,170
Cereal rye	R8	2,170	4,697	5,703	3,799
LSD (0.05)	-	NS	NS	NS	NS

Table 7. Crude protein of annual ryegrass and cereal rye overseeded at different soybean reproductive stages and harvested during Year 1 and Year 2. Autumn, spring, and annual average crude protein data is weighted according to the quantity harvested during each period. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Year 1			Year 2		
		Autumn	Spring	Annual average	Autumn	Spring	Annual average
		$g\ kg^{-1}$					
Annual ryegrass	R5.5	284	184	201	299	194	243
Cereal rye	R5.5	284	174	209	314	189	224
Annual ryegrass	R6.5	275	173	219	279	193	230
Cereal rye	R6.5	313	175	207	305	180	214
Annual ryegrass	R8	278	170	197	297	208	234
Cereal rye	R8	-	175	175	301	187	219
LSD (0.05)	-	16	NS	16	NS	NS	20

Table 8. Acid detergent fiber of annual ryegrass and cereal rye overseeded at different soybean reproductive stages and harvested during Year 1 and Year 2. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle. Autumn, spring, and annual average acid detergent fiber data is weighted according to the quantity harvested during each period.

Species	Reproductive Stage of Soybean	Year 1			Year 2		
		Autumn	Spring	Annual average	Autumn	Spring	Annual average
		$g\ kg^{-1}$					
Annual ryegrass	R5.5	172	200	196	200	232	216
Cereal rye	R5.5	200	269	247	207	293	269
Annual ryegrass	R6.5	178	202	191	214	230	224
Cereal rye	R6.5	181	275	253	212	296	273
Annual ryegrass	R8	190	197	195	213	218	216
Cereal rye	R8	-	263	263	199	291	265
LSD (0.05)	-	NS	23	19	NS	14	14

Table 9. Neutral detergent fiber of annual ryegrass and cereal rye overseeded at different soybean reproductive stages and harvested during Year 1 and Year 2. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle. Autumn, spring, and annual average nuetral detergent fiber data is weighted according to the quantity harvested during each period.

Species	Reproductive Stage of Soybean	Year 1			Year 2		
		Autumn	Spring	Annual average	Autumn	Spring	Annual average
				g kg^{-1}			
Annual ryegrass	R5.5	544	548	547	546	550	548
Cereal rye	R5.5	544	556	552	544	559	555
Annual ryegrass	R6.5	543	548	546	547	550	549
Cereal rye	R6.5	541	558	554	543	559	554
Annual ryegrass	R8	545	547	547	548	548	548
Cereal rye	R8	-	556	556	544	559	555
LSD (0.05)	-	NS	3	3	3	3	2

Table 10. Weed cover in the autumn and spring of Year 1 and Year 2 of annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle. Plots were rated visually on a 0 to 100 scale.

Species	Reproductive Stage of Soybean	Autumn Year 1	Autumn Year 2	Spring Year 1	Spring Year 2
		%			
Annual ryegrass	R5.5	27	8	17	2
Cereal rye	R5.5	6	3	5	1
Annual ryegrass	R6.5	17	4	7	1
Cereal rye	R6.5	23	1	7	0
Annual ryegrass	R8	12	8	12	3
Cereal rye	R8	14	12	7	3
Control	-	22	13	76	31
LSD (0.05)	-	11	8	8	11

Table 11. Number of weeds m^{-2} in the spring of annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Year 1	Year 2
		weeds m^{-2}	
Annual ryegrass	R5.5	430	10
Cereal rye	R5.5	150	10
Annual ryegrass	R6.5	270	30
Cereal rye	R6.5	300	0
Annual ryegrass	R8	310	20
Cereal rye	R8	240	30
Control	-	490	120
LSD (0.05)	-	160	50

Table 12. Root mass in the soil profile in the spring of Year 1 of annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle.

Species	Reproductive Stage of Soybean	Year 1					
		Depth in cm					
		0-2	2-15	15-30	30-45	45-100	0-100
		$g\ m^{-3}$					
Annual ryegrass	R5.5	234	21	3	2	3	263
Cereal rye	R5.5	96	14	3	2	3	118
Annual ryegrass	R6.5	182	26	5	4	2	219
Cereal rye	R6.5	73	20	3	2	3	101
Annual ryegrass	R8	176	25	4	2	3	210
Cereal rye	R8	78	20	2	2	2	104
LSD (0.05)	-	84	NS	NS	NS	NS	NS

Table 13. Root mass in the soil profile in the spring of Year 2 of annual ryegrass and cereal rye overseeded into soybean at different reproductive stages. Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Year 2					
		Depth in cm					
		0-2	2-15	15-30	30-45	45-100	0-100
		——— g m^{-3} ———					
Annual ryegrass	R5.5	186	24	3	7	4	224
Cereal rye	R5.5	149	32	2	2	3	188
Annual ryegrass	R6.5	214	20	3	1	2	240
Cereal rye	R6.5	145	45	4	1	2	197
Annual ryegrass	R8	128	21	4	2	2	157
Cereal rye	R8	216	16	2	4	3	241
LSD (0.05)	-	NS	NS	NS	NS	NS	NS

Table 14. Mass of corn roots through the soil profile following annual ryegrass and cereal rye treatments that had been overseeded at different soybean reproductive stages in Year 1. Year 1 was for the 2003-2004 cycle.

Species of forage that corn was planted after	Reproductive Stage of Soybean	Year 1					
		Depth in cm					
		0-2	2-15	15-30	30-45	45-100	0-100
		$g\ m^{-3}$					
Annual ryegrass	R5.5	125	41	5	3	1	175
Cereal rye	R5.5	81	42	7	4	1	135
Annual ryegrass	R6.5	84	40	9	6	1	140
Cereal rye	R6.5	215	41	5	2	1	264
Annual ryegrass	R8	109	40	5	2	1	157
Cereal rye	R8	83	59	7	2	1	152
Control	-	104	23	4	3	1	135
LSD (0.05)	-	NS	NS	NS	NS	NS	NS

Table 15. Percent residue cover after corn planting in Year 1 and Year 2 of treatments that had annual ryegrass and cereal rye overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species	Reproductive Stage of Soybean	Year 1	Year 2
		%	
Annual ryegrass	R5.5	61	61
Cereal rye	R5.5	53	52
Annual ryegrass	R6.5	67	52
Cereal rye	R6.5	53	65
Annual ryegrass	R8	68	57
Cereal rye	R8	58	52
Control	-	20	16
LSD (0.05)	-	10	7

Table 16. Corn population in the spring of Year 1 and Year 2 following annual ryegrass and cereal rye that had been overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle and Year 2 was for the 2004-2005 cycle.

Species corn was planted after	Reproductive Stage of Soybean	Year 1	Year 2
		plants ha^{-1}	
Annual ryegrass	R5.5	61,700	53,204
Cereal rye	R5.5	61,454	58,984
Annual ryegrass	R6.5	52,759	63,331
Cereal rye	R6.5	56,958	60,021
Annual ryegrass	R8	63,331	55,130
Cereal rye	R8	63,330	61,997
Control	-	56,958	60,564
LSD (0.05)	-	NS	NS

Table 17. Corn yield in the autumn of Year 1 following annual ryegrass and cereal rye that had been overseeded at different soybean reproductive stages. Year 1 was for the 2003-2004 cycle.

Species corn was seeded after	Reproductive Stage of Soybean	Year 1
		kg ha^{-1}
Annual ryegrass	R5.5	9,237
Cereal rye	R5.5	8,517
Annual ryegrass	R6.5	8,702
Cereal rye	R6.5	8,290
Annual ryegrass	R8	8,934
Cereal rye	R8	8,685
Control	-	9,244
LSD (0.05)	-	NS