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An Agronomic and Economic Analysis of Annual Ryegrass Management Practices in North-Texas Soybean Production

Jose A. Lopez, Henry J. Flowers, and David R. Drake

An analysis of the effect of pre-season ryegrass management practices including herbicides, forage utilization and cover cropping on no-till soybean yield, grain density, and height. The profitability of forage utilization based on production and price is explored. Annual ryegrass is a cool-season annual bunchgrass, which due to its high palatability and digestibility is valuable for forage. Grazing cover crops is economically viable when the returns offset establishment costs without reducing crop yields. Six ryegrass management practices prior to planting soybean were evaluated: volunteer ryegrass as a cover crop, ryegrass forage harvested for hay, ryegrass forage grazing simulation, and three different herbicides applications that vary in timing (December, February, and March application). All forage and cover crop plots were terminated with glyphosate or paraquat two weeks prior to planting soybeans. There were no statistical differences in soybean yields, soybean height, and soybean grain density between annual ryegrass cover cropping and herbicide treatments averaged over the two years evaluated. The results also indicated that ryegrass forage can produce up to 2,741 kg ha^{-1} of dry matter that if sold as hay can generate a profit between \$230 and \$244 ha^{-1}. Similarly, if land is leased for grazing, ryegrass could generate a profit of \$63 ha^{-1} if its dry matter production is 1,006.70 kg.

***Key words**:* Cover Crop, Forage, Grazing, Hay, No-till Soybeans

According to the United States Department of Agriculture (USDA) Farm Service Agency (FSA) (USDA, 2021a), 70% of the farmlands in the United States produce corn and soybean (Figure 1) with 82-94% using crop rotations (Wallander, 2013) and only 3-7% of the farms using cover crops. Crop rotation is a regenerative agriculture practice, while cover crops can improve soil and water quality. Crop rotation and cover cropping can have many benefits combined.

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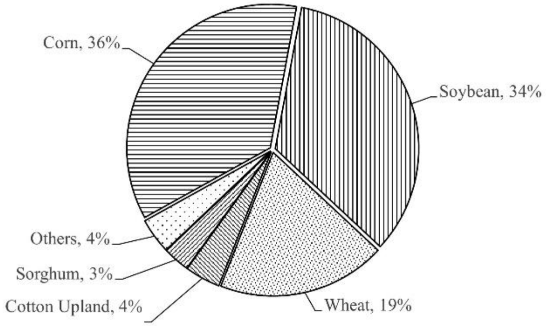

Figure 1. Planted acres in the United States, 2011. *Source: USDA (2021a).*

Cover crops

Cover crops are used to cover the soil before the cash-crop season starts. The use of cover crops increased 50% from 2012 to 2017 (Wallander et al., 2021). The benefits attributed to cover crops include soil health enhancement, erosion prevention, soil moisture conservation, water quality protection, personal health safeguard, and less use of fertilizers, herbicides, and pesticides (Clark, 2012). Cover crops can either help to enrich the soil with nitrogen or scavenge for excess of it (Clark, 2012). Covering the soil with a cover crop reduces the appearance of weeds and potential pests associated with those weeds. Yield improvements in the cash crops due to cover crops are possible since the roots of the cover crops can facilitate infiltration, relieve compaction, and improve soil structure. The vegetative portion of the cover crop contributes to the organic matter of the soil, encouraging microbial life and enhancing the nutrient cycle (Clark, 2012).

Cover crops are beneficial for soil and water conservation when incorporated in a rotation system. Ryegrass is ideal as a winter cover crop because of its hardiness (Ditscha and Alley, 1991). Acharya et al. (2019) reported that cover cropping increased soybean yield while it did not have an effect on soybean height, but that it depends on the tillage system and the cover crop. Rye is also good for mulching in no-till soybean (Eckert, 1988). However, decomposing cereal rye residues have allelopathic effects on other plant species, such as retarding their growth and development (Rice, 1995). Ryegrass residuals can also decrease the seed number that reaches the soil in corn and soybean rotations (Eckert, 1988). Ryegrass decomposition can also immobilize inorganic nitrogen and therefore decrease corn grain yield (Blevins, Herbek, and Fyre, 1990).

Grazing cover crops could encourage cover crop adoption if returns offset establishment costs without decreasing yields (Schomberg et al., 2014). Grazing winter rye cover crop in a cotton no-till system can increase profits but have a negative effect on soil compaction (Schomberg et al., 2014). Farmers can receive an additional \$110 ha^{-1} between grazed and non-grazed land (Schomberg et al., 2014). A corn-ryegrass-soybean rotation can increase Nitrous oxide (N2O) emission, but a rotation soybean-ryegrass-corn may have no impact on N2O emissions (Smith et al., 2011). Winter ryegrass cover crop as part of a corn-soybean crop rotation can improve the soil-water dynamics without sacrificing the cash crop growth (Basche et al., 2016). On corn systems, ryegrass is an ideal cover crop because it can conserve inorganic Nitrogen while having no effect on yield (Snapp and Surapur, 2018).

Annual ryegrass forage

Annual ryegrass is one of the best cool season grasses because of its amount of protein, digestibility, vitamins, minerals and palatability in its leafy stage (Lacefield et al., 2003). From initial growth until the seed heads emerge, annual ryegrass pastures can have 20% of crude protein and 70% of total digestibility (McCormick, Cuomo, and Blouin, 2013). It can provide up to 10% of crude protein and 55% of total digestible nutrients even if harvested for hay at a late maturity stage (McCormick, Cuomo, and Blouin, 2013). Beef cattle with annual ryegrass as the main feed source can exhibit daily gains of 0.82-1.00 kg while dairy with adequate milking potential can exhibit daily milk production of 15.86-18.14 kg (Lacefield et al., 2003). Grazed annual ryegrass is a viable cover crop option for integrated crop-livestock systems, with 12-18 cm being the ideal sward heights to optimize forage production and animal performance while keeping adequate residual soil cover (Planisich at al., 2021). Stocking rates are very important when grazing cover crops. Lower stocking rates and grazing intensities can increase voluntary intake of cover crops and animal weight gains (Cangiano et al., 2002; Carvalho et al., 2010). However, higher grazing intensities and stocking rates can also have negative repercussions on daily gains, future cash-crop yield, and soil compaction (Planisich et al., 2021).

Ryegrass hay price can range between \$185 and \$200 t^{-1} depending on the quaility (USDA, 2021b). Farmers can also lease their land for grazing. Texas fixed leasing rates in 2020 were \$234.75 ha^{-1} for irrgated cropland, \$74.13 ha^{-1} for non-irrigated cropland, and \$17.30 ha^{-1} for pastureland (Dowell, 2020).

Soybean and rygrass cropping system

In 2018, ryegrass was one of the most common cover crops on soybean systems (Figure 2). The United States is the number one producer of soybeans in the world and the second largest exporter (Bowman and Wallander, 2021). In 2021, the U.S. soybean production was 119.75 billion kg with a density of 3456.7 kg ha^{-1} (Barret, 2022).

The start of the soybean season in Texas ranges from the middle of May to early July (Bean and Miller, 1998). Since soybean takes 80-120 days until harvest, the soybean season ends around Sepetember to early November. Farmers who only grow soybeans will therefore not farm for at least about half of the year, but they still need to use chemicals for weed control. This study evaluates the use of volunteer annual ryegrass as a cover crop and as a forage. Farmers can increase their sustainability and become more environmentally friendly by commercializing annual ryegrass during late fall and spring, rather than treating it as a weed. Farmers have the potential to reduce herbicide and pesticide use and add an extra source of income from cover cropping annual ryegrass.

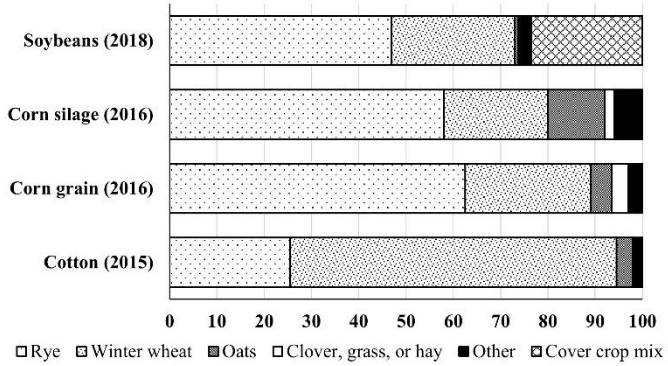

Figure 2. Cover crops used in the United States in cotton, corn grain, corn silage, and soybean from 2015 to 2018.

Source: Bowman and Wallander (2021). Note: For all years, rye includes both cereal rye and annual ryegrass. Cover crop mix was not a reporting option in 2015 and 2016.

Burndown and no-tillage systems

Burndown herbicides are critical to terminate the cover crop and early season weeds prior to the cash crop establishment (Price and Kelton, 2013). Residual herbicides are also recommended in order to extend weed control into the season (Price and Kelton, 2013). Annual ryegrass can resist herbicides like glyphosate (Singh et al., 2020), so a product rotation with different active ingredients is important. However, the control of grass cover crop species seems to be best with glyphosate alone or combined with 2,4-D, dicamba, or saflufenacil; herbicides like paraquat and glufosinate do not seem to provide adequate annual ryegrass control (Cornelius and Bradley, 2017). The best control of annual ryegrass can be achieved with a high dose of glyphosate applied at the early flower stage but biomass reduction of the annual ryegrass cover crop may occur (Lins et al., 2007).

Tillage is also important when establishing crops. In 2004, 25.25 million hectares in the U.S. used no-tillage for crop production (Iowa State University, 2021). Around 4.13 million hectares are used for soybean and one third of those use no-tillage systems (Iowa State University, 2021). No-tillage crop production has been increasing at a 5% rate since 2002 (Iowa State University, 2021). Soybean yield in no-tillage systems may increase (Pedersen and Lauer, 2003) or decrease (Vasilas et al., 1988) when compared to tillage systems. Pedersen and Lauer (2003) observed a 6% yield increase in soybean planted in a no-tillage system when compared to a conventional tillage system in long-term rotation systems, while Vasilas et al. (1988) observed a yield decrease when compared to various tillage system.

Purpose of the study

Farmers can reduce herbicide use and costs by using cover crops. About 65% of the pesticide expenditures used by U.S. farmers are herbicides for weed control (Farm Progress Network, 2005). This study analyzes alternatives for a more efficient use of soybean cropping land during fall and spring. The use of volunteer annual ryegrass as a cover crop in no-till soybean is evaluated along with the economic viability of using ryegrass as a forage. The study evaluates if having soybean and ryegrass on a system is more profitable than soybean without a cover crop; and if there is no impact on the soybean yield, grain density, and height when stablished in a system with ryegrass.

Table 1. Annual Ryegrass Management Practices Evaluated.

Treatment	Description
1	Volunteer annual ryegrass cover crop (cover cropping).
2	Annual ryegrass forage harvested as hay (hay production).
3	Annual ryegrass forage harvested in early spring (grazing simulation).
4	Glyphosate or paraquat application in December.
5	Glyphosate or paraquat application in February.
6	Glyphosate or paraquat application in March.

Materials and Methods

The experiment was conducted on a Leson clay soil in Greenville, Texas (33°9’59”N 96°9’51”W). Leson clay is moderately well drained with very low to moderately low permeability (0.00 to 1.53 cm hr^{-1}), expansive under moist conditions and significantly cracky under dry conditions. Volunteer annual ryegrass is already established in the soil; that is, there was no need for seeding annual ryegrass because it is a difficult weed to control in the preceding wheat crop. Six ryegrass management practices (treatments) prior to the start of the soybean crop season were evaluated (Table 1) for two years (2021 and 2022). The first treatment consisted of leaving volunteer ryegrass to grow in the plot through the fall and spring season (i.e., cover cropping). The second treatment consisted in leaving ryegrass in fall but harvesting it for hay in late spring (i.e., April). The third treatment consisted in an early ryegrass forage cut to simulate grazing in early spring (i.e., January). The fourth, fifth, and sixth treatments consisted of a single herbicide application (paraquat or glyphosate) during a traditional month (December, February or March) to terminate ryegrass. The difference between the fourth, fifth, and sixth treatments is the time of the herbicide application. Treatment 4 consists of an early application, while treatments 5 and 6 are intermediate and late applications, respectively. The experiment consisted of a complete randomized-block design with 4 replications per treatment where each plot was 1.5 m in width and 6.1 m in length. Figure 3 reports a timeline for each of the treatments. Treatments 1, 2, and 3 all require that ryegrass be terminated with a herbicide application early in June prior to start soybean seeding in late June (Figure 3).

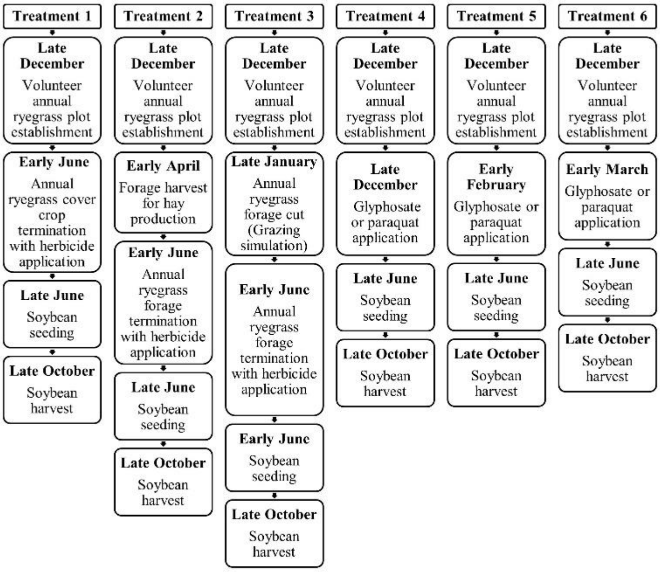

Figure 3. Timeline of ryegrass management practices evaluated.

All forage and cover crop plots (treatments 1 through 3) were terminated with glyphosate or paraquat at least 2 weeks prior to planting soybean. The study does not aim to verify the efficiency of the herbicide treatments, but to compare the impact of ryegrass cover cropping, forage, and grazing on the future soybean production with herbicide applications, which is what farmers conventionally do to their land offseason.

The four main variables collected in this study were annual ryegrass forage, soybean yield, soybean height, and soybean grain density (test weight). Annual ryegrass forage production data was collected twice a year, first for the grazing simulation (January) and second for the hay production treatments (April). Forage was harvested, weighed, dried, and weighted to obtain dry matter production. Plots with ryegrass forage production (treatments 2 and 3) were clipped and weighed to calculate forage production potential. Clipping was done using a Black and Decker electric battery powered hedge trimmer at a 7.6-centimeters height. Forage was stored in paper bags and then weighted on a platform scale.

Dry matter was calculated to estimate the amount of ryegrass hay production. First, forage bags (from treatments 2 and 3) were weighted, and a 600-gram sample was taken from each of them. Second, the humidity in the 600-gram samples was extracted by using a forced air oven at 344.3 °K for 48 hours. After the samples were weighted again, weeds were extracted and weighted. The weed weight was subtracted from the dry forage weight to calculate clean dry forage. The percentage of dry clean forage was calculated by dividing the quantity of clean dry forage by the initial 600-grams weight. Last, the percentage of dry clean forage was multiplied by the total weigh in the forage bag to obtain total dry matter production per plot.

Herbicide treatments were applied using a broadcast sprayer with a 1.52 meters hand boom and CO_2 propellant at 241.3 kilopascals (35 PSI). Paraquat and glyphosate application rates were 2.35 litters ha^{-1}.

Soybeans were seeded in June 2021 and 2022 with a glyphosate and dicamba tolerant variety (Asgrow AG49X). Soybean plots received a post emergent application of glyphosate, s-metolachlor, and dicamba to control weeds until harvest. Soybean seed was harvested in October 2021 and 2022 with a plot combine and stored in paper bags, then cleaned and weighed using a regular platform scale to obtain soybean yield. Soybean height was calculated by measuring five plants in each plot prior to harvest. Grain density was determined by using the test weight method, which consists of pouring soybean seed into a pint cup using a funnel, followed by scalping off the excess grain by doing three equal zigzag movements with a hardwood striker. Finally, the seed density was calculated from the grain weight necessary to fill a pint cup, yielding test weight.

Table 2. Costs and Earnings Considered for the Sensitivity Analyses of Hay Production.

Description	US Dollars	Description
Costs		
Grass seeding rate	53.23	ha^{-1}
Herbicides flat rate ground application	24.98	ha^{-1}
Paraquat	18.61	2.35 litters ha^{-1}
Glyphosate	33.06	2.35 litters ha^{-1}
Crop production consulting services	19.77	ha^{-1}
Ryegrass seed	43.24	28.02 kg ha^{-1}
Round bales over 680 kg full wrap	117.18	2,741.60 kg ha^{-1}
Hauling hay (field to storage)	27.04	2,741.60 kg ha^{-1}
Total cost with paraquat	304.05	ha^{-1}
Total cost with glyphosate	318.50	ha^{-1}
Earnings		
Hay price (good quality, 23% protein)	0.20	kg^{-1}
Hay production		2,741.60 kg ha^{-1}
Total earnings	548.32	ha^{-1}
Total profit using paraquat	244.27	ha^{-1}
Total profit using glyphosate	229.82	ha^{-1}

Notes: Custom rates from Texas Agriculture Custom Rates (Klose, 2020). Commercial herbicide prices from FBN (2022).

Northeast Texas is a low-soybean-yield and high temperature environment. The area is characterized by rain-fed agriculture; excessive rainfall in winter and early spring followed by prolonged periods of heat and dryness in summer. It is a high transpiration environment, hot and windy. Choosing the right crops is crucial in dryland agriculture. In addition, by adopting appropriate management practices, farmers can more efficiently use their resources and improve their resilience to environmental challenges.

In general, soybean yields less in hot climates due to stress, and reduced soil transpiration and water use; resulting in less efficiency and lower yields. The study examines potential variations in soybean yield, height, and seed density over a two year-period to ascertain the consistency of results. Soybean yield in 2022 was lower than 2021 because of rainfall and late planting. The year 2021 was an above-average year while the year 2022 was a below-average year. It's not uncommon to have such variations in yield in a low-soybean-yield environment. Provided that ryegrass is already established in the research area as weeds in the prior year's wheat crop, the study aimed to determine whether the impact of selective ryegrass management practices on soybean varied from one year to the next.

Table 3. Costs, Earnings, and Other Variables Considered for the Sensitivity Analysis of Grazing Simulation.

Description	US Dollars	Description
Costs		
Grass seeding rate	53.23	ha^{-1}
Herbicides flat rate ground application	24.98	ha^{-1}
Crop production consulting services	19.77	ha^{-1}
Ryegrass seed	43.24	28.02 kg ha^{-1}
Paraquat	18.61	2.35 litters ha^{-1}
Total cost	159.83	ha^{-1}
Earnings		
Cattle grazing lease contract	1.33	kg^{-1} on weight gain
Quantity of dry matter produced		503.35 kg per cycle
Cycles of ryegrass		2 cycles
Calf daily intake		6.8 kg (3% of weight)
Days of occupancy		148 days (226.8 kg calf)
Daily weight gain per animal		1.13 kg
Weight gain per animal over 148 days		167.29 kg
Total earnings	223.05	ha^{-1}
Total profit	63.22	ha^{-1}

Notes: Custom rates from Texas Agriculture Custom Rates (Klose, 2020). Commercial Herbicide prices from FBN (2022).

An analysis of variance (ANOVA) and Tukey pairwise mean comparisons were conducted using proc GLM in Statistical Analysis System software (SAS) version 9.4 to determine if there were statistical differences in soybean yield, height, and grain density among treatments. In addition, three sensitivity analyses using the 2020 Texas Agricultural Custom Rates and commercial herbicide prices from Farmers Business Network (2022), were conducted to determine if it is viable to harvest ryegrass as hay and for grazing (Table 2). Two sensitivity analyses were done for hay production (treatment 2), one terminating ryegrass after harvest with glyphosate and the other with paraquat (Gramoxone). A third sensitivity analysis was done for the grazing simulation (treatment 3) to determine the potential profit of grazing lightweight calves (226.8 kg). Ryegrass intake and daily gain were assumed to be 3.0% of animal weight (Schwab 2010) and 1.13 kg (Filley and Mueller, 2013). Two cycles of grazing were considered in the analysis due to annual ryegrass 4-weeks regrow cycle (Oregon State University 2022); therefore, the dry matter calculation for the grazing simulation (treatment 3) assumes two grazing cycles before soybean establishment in late June. Costs, earnings, and other variables used for the grazing sensitivity analyses are reported in Table 3. Ryegrass seed costs and establishment costs were considered in the sensitivity analysis at a rate of 28.02 kg ha^{-1} (Speir and Hancock, 2017).

Table 4. Least-Squares Mean Comparisons for Soybean Yield.

Treatment	**2021**			**2022**		**Overall**	
	LSMEAN --- kg ha^{-1} ---			**LSMEAN** --- kg ha^{-1} ---		**LSMEAN** --- kg ha^{-1} ---	
3	1488.89	A		158.64	A	823.76	A
6	1347.23	A	B	158.65	A	572.07	A
2	1304.02	A	B	136.05	A	854.80	A
5	1166.60	A	B	227.93	A	728.55	A
1	1138.85	A	B	106.07	A	582.74	A
4	919.08		B	233.83	A	599.29	A

Note: Treatments with different letters are statistically different at a 0.05 significance level.

Results and Discussion

Soybean yield averages 3,456.7 kg ha^{-1} in the United States but in Texas it is estimated to be a little lower with a production of 2,555.5 kg ha^{-1} (Barrett, 2022). Due to high temperatures and lack of precipitation in North Texas during seed fill, soybean yields in this study do not exceed 1,488.9 kg ha^{-1} (Table 4). In addition, the study did not irrigate and fertilize soybean because its main focus is on evaluating the selected ryegrass management practices (Table 1).

In 2021, the ANOVA test (Table 8) for soybean yield obtained a p-value of 0.0317, suggesting that at least one of the soybean yield treatment means is different from the others. Table 4 reports soybean yield (kg ha^{-1}) per treatment by year. In 2021, the grazing simulation (treatment 3) resulted on an average soybean yield of 1,488.89 kg ha^{-1} that was statistically different at a 0.05 significance level from glyphosate or paraquat application in December (treatment 4) that resulted on an average soybean yield of 919.08 kg ha^{-1}. In 2022, the ANOVA test (Table 8) for soybean yield obtained a p-value of 0.0389 suggesting that at least one of the soybean yield treatment means is different from the others. In 2022, volunteer annual ryegrass cover crop (treatment 1) that resulted in an average soybean yield of 106.07 kg ha^{-1} was at the margin of being statistically different at the 0.05 significant level (p-value 0.0551) from glyphosate or paraquat application in December (treatment 4) that resulted on an average soybean yield of 233.83 kg ha^{-1}. The soybean is expected to be grade 4; therefore, it may be discounted between \$0.00018 and \$0.00073 kg^{-1} for each kilogram below the standard weight (Heatherly, 2015).

Table 5. Sensitivity Analysis for Seeded Annual Ryegrass Hay Production Terminated with Paraquat Contact Herbicide (Conservative Scenario).

Hay price -- $ kg⁻¹ --	Dry mater production --- kg ha⁻¹ ---					
	1000.00	**1500.00**	**2000.00**	**2741.60**	**3000.00**	**3500.00**
$0.100	*($204.05)*	*($154.05)*	*($104.05)*	*($29.89)*	*($4.05)*	$45.95
$0.125	*($179.05)*	*($116.55)*	*($54.05)*	$38.65	$70.95	$133.45
$0.150	*($154.05)*	*($79.05)*	*($4.05)*	$107.19	$145.95	$220.95
$0.175	*($129.05)*	*($41.55)*	$45.95	$175.73	$220.95	$308.45
$0.200	*($104.05)*	*($4.05)*	$95.95	**$244.27**	$295.95	$395.95
$0.225	*($79.05)*	$33.45	$145.95	$312.81	$370.95	$483.45
$0.250	*($54.05)*	$70.95	$195.95	$381.35	$445.95	$570.95
$0.275	*($29.05)*	$108.45	$245.95	$449.89	$520.95	$658.45
$0.300	*($4.05)*	$145.95	$295.95	$518.43	$595.95	$745.95
$0.325	$20.95	$183.45	$345.95	$586.97	$670.95	$833.45
$0.350	$45.95	$220.95	$395.95	$655.51	$745.95	$920.95

Note: The conservative scenario includes seeding rate and seed price in the profit ($ ha $^{-1}$) calculations reported inside the table.

Table 6. Sensitivity Analysis for Seeded Annual Ryegrass Hay Production Terminated with Glyphosate Systemic Herbicide (Conservative Scenario).

Hay price -- $ kg⁻¹ --	Dry mater production --- kg ha⁻¹ ---					
	1000.00	**1500.00**	**2000.00**	**2741.60**	**3000.00**	**3500.00**
$0.100	*($218.50)*	*($168.50)*	*($118.50)*	*($44.34)*	*($18.50)*	$31.50
$0.125	*($193.50)*	*($131.00)*	*($68.50)*	$24.20	$56.50	$119.00
$0.150	*($168.50)*	*($93.50)*	*($18.50)*	$92.74	$131.50	$206.50
$0.175	*($143.50)*	*($56.00)*	$31.50	$161.28	$206.50	$294.00
$0.200	*($118.50)*	*($18.50)*	$81.50	**$229.82**	$281.50	$381.50
$0.225	*($93.50)*	$19.00	$131.50	$298.36	$356.50	$469.00
$0.250	*($68.50)*	$56.50	$181.50	$366.90	$431.50	$556.50
$0.275	*($43.50)*	$94.00	$231.50	$435.44	$506.50	$644.00
$0.300	*($18.50)*	$131.50	$281.50	$503.98	$581.50	$731.50
$0.325	$6.50	$169.00	$331.50	$572.52	$656.50	$819.00
$0.350	$31.50	$206.50	$381.50	$641.06	$731.50	$906.50

Note: The conservative scenario includes seeding rate and seed price in the profit ($ ha $^{-1}$) calculations reported inside the table.

Table 7. Sensitivity Analysis for Seeded Annual Ryegrass Grazing Simulation Terminated with Paraquat Contact Herbicide (Conservative Scenario).

Grazing rate -- $ kg-1 gain--	Dry mater production --- kg ha^{-1} ---					
	600.00	**800.00**	**1006.70**	**1200.00**	**1400.00**	**1600.00**
$0.89	*($71.20)*	*($41.66)*	*($11.13)*	$17.42	$46.97	$76.51
$1.00	*($60.12)*	*($26.89)*	$7.46	$39.58	$72.82	$106.05
$1.11	*($49.05)*	*($12.12)*	$26.05	$61.74	$98.67	$135.59
$1.22	*($37.97)*	$2.65	$44.64	$83.90	$124.52	$165.14
$1.33	*($26.89)*	$17.42	**$63.22**	$106.05	$150.37	$194.68
$1.44	*($15.81)*	$32.20	$81.81	$128.21	$176.22	$224.22
$1.56	*($4.73)*	$46.97	$100.40	$150.37	$202.07	$253.76
$1.67	$6.35	$61.74	$118.99	$172.52	$227.92	$283.31
$1.78	$17.42	$76.51	$137.57	$194.68	$253.76	$312.85
$1.89	$28.50	$91.28	$156.16	$216.84	$279.61	$342.39
$2.00	$39.58	$106.05	$174.75	$238.99	$305.46	$371.93

Note: The conservative scenario includes seeding rate and seed price in the profit calculations ($ ha $^{-1}$) reported inside the table.

Table 8. ANOVA Test for Soybean Yield (kg ha-^{1}) Using the GLM Procedure.

Source	**DF**	**Sum of squares**	**Mean square**	**F value**	**Pr > F**
		2021			
Model	5	1590654.54	318130.91	2.71	0.0317
Error	46	5407739.67	117559.56		
Corrected total	51	6998394.21			
		2022			
Model	5	113944.56	22788.91	2.56	0.0389
Error	50	445631.24	8912.62		
Corrected total	55	559575.8			
		Overall			
Model	5	1367010.54	273402.11	0.77	0.5768
Error	102	36434420.45	357200.2		
Corrected total	107	37801430.99			
Year	**R-square**	**Coeff var**	**Root MSE**	**Yield (kg ha^{-1})**	
2021	0.2273	28.0896	342.8696	1220.63	
2022	0.2036	58.4408	94.4067	161.54	
Overall	0.0362	89.0076	597.6623	671.47	

The ANOVA test for soybean height, obtained a p-value of 0.2874 in 2021 and 0.0822 in 2022, indicating no statistical differences in soybean heights among the treatment means, and suggesting the annual ryegrass management practices do not affect the height of the soybean plants. Overall, an average height of 56.84 cm was obtained across all treatments (an average height of 53.52 cm in 2021 and 59.57 cm in 2022). The soybean height measurements for all treatments evaluated in this experiment are below the U.S. national average, which varies from 91.4 to 152.4 cm.

Similarly, overall and by year, there were no statistically significant differences for the soybean density test weight across treatments at a 0.05 significance level. This suggests the annual ryegrass management practices do not affect seed density. Overall, treatments reported a mean test weight of 23.08 kg bu^{-1} (an average weight of 23.47 kg bu^{-1} in 2021 and 22.54 kg bu^{-1} in 2022). Soybean standard test weight is 27.22 kg bu^{-1} and some elevators can reject loads with test weights below 22.23 kg bu^{-1} (Heatherly, 2015).

In general, the lower soybean yield and height in year 2 was attributed to lower rainfall and late planting. Despite this yield decrease, the test weight remained consistent with the U.S. standard at 22.54 kg bu^{-1}, indicating stable soybean quality. Furthermore, the grazing simulation and the December herbicide application were statistical insignificant. In addition, the cover-cropping treatment consistently performed on par with other treatments over time, suggesting that this soil-conserving practice does not compromise profitability. This outcome reflects a beneficial synergy between farmers and the environment, reducing the necessity for pesticides. Ryegrass dry matter averaged 2,741.60 kg ha^{-1} from hay production (treatment 2). Given the hay prices and costs in Table 2, ryegrass hay production has the potential to generate a profit of \$244.27 ha^{-1} when using paraquat to terminate ryegrass crop residues before stablishing soybean, and \$229.82 ha^{-1} when using glyphosate. Sensitivity analysis for ryegrass demonstrated that if hay prices drop to \$0.10 kg^{-1}, ryegrass production will not be profitable (Table 5). Similarly, at a hay price of \$0.20 kg^{-1}, if ryegrass dry matter production decreases to 1500 kg ha^{-1}, ryegrass hay production will not be profitable (Table 5). The values in italics or negative numbers between parenthesis in Table 5 (paraquat analysis) and Table 6 (glyphosate analysis) represent all unprofitable situations for farmers, considering hay prices and dry matter production as sensitive variables while holding everything else in Table 2 constant. The values in bold in Tables 5 and 6 correspond to the baseline (Table 2), which consists of 2,741.60 kg of annual ryegrass dry matter produced at a hay price of \$0.20 kg^{-1}.

In the grazing simulation (treatment 3) annual ryegrass produced 503.35 kg ha^{-1} of dry matter over 1 cycle of regrowth, which is 1006.70 kg ha^{-1} total (i.e., over 2 cycles). Total costs were estimated to be \$159.83 and revenues to be \$223.05 ha^{-1} (Table 3). A total profit of \$63.22 ha^{-1} could be generated from leasing the land for stockers, feeder cattle, or beef cows to feed on ryegrass at a rate of \$1.33 kg^{-1} on added weight the livestock gains (Hofstrand and Edwards, 2015) over a period of 148 days. The sensitivity analysis shows that the leasing rate on weight gain cannot be less than \$1.00 kg^{-1} in order to make a profit, at an overall dry matter production of 1006.70 kg (Table 7). Similarly, dry matter production cannot be lower than 800 kg ha^{-1} at a leasing rate of \$1.33 kg^{-1} on weight gain in order to make a profit (Table 7). Table 7 shows many possible scenarios for various total dry matter production levels and leasing rates. The values in italic or negative numbers between parentheses in Table 7 are all scenarios that will not be profitable at the corresponding land leasing rate and dry matter production level and holding everything else in Table 3 constant. The values in bold in Table 7 correspond to the baseline scenario (Table 3).

The results from the sensitivity analyses are conservative because the costs of seed and seeding rate were considered in the profit calculation as indicated in Tables 2 and 3. The conservative scenario refers to farms who do not have annual ryegrass voluntarily growing. The sensitivity analyses reported in Tables 9 through 11 report the results from an optimistic scenario, which is when farms already have volunteer annual ryegrass growing. Therefore, the sensitivity analyses in Tables 9 through 11 excludes seed costs and seeding rate and results in higher profits.

Table 9. Sensitivity Analysis for Volunteer Annual Ryegrass Hay Production Terminated with Paraquat Contact Herbicide (Optimistic Scenario).

Hay price -- \$ kg^{-1} --	**Dry mater production --- kg ha^{-1} ---**					
	1000.00	**1500.00**	**2000.00**	**2741.60**	**3000.00**	**3500.00**
\$0.100	*(\$107.58)*	*(\$57.58)*	*(\$7.58)*	\$66.58	\$92.42	\$142.42
\$0.125	*(\$82.58)*	*(\$20.08)*	\$42.42	\$135.12	\$167.42	\$229.92
\$0.150	*(\$57.58)*	\$17.42	\$92.42	\$203.66	\$242.42	\$317.42
\$0.175	*(\$32.58)*	\$54.92	\$142.42	\$272.20	\$317.42	\$404.92
\$0.200	*(\$7.58)*	\$92.42	\$192.42	**\$340.74**	\$392.42	\$492.42
\$0.225	\$17.42	\$129.92	\$242.42	\$409.28	\$467.42	\$579.92
\$0.250	\$42.42	\$167.42	\$292.42	\$477.82	\$542.42	\$667.42
\$0.275	\$67.42	\$204.92	\$342.42	\$546.36	\$617.42	\$754.92
\$0.300	\$92.42	\$242.42	\$392.42	\$614.90	\$692.42	\$842.42
\$0.325	\$117.42	\$279.92	\$442.42	\$683.44	\$767.42	\$929.92
\$0.350	\$142.42	\$317.42	\$492.42	\$751.98	\$842.42	\$1,017.42

Note: The optimistic scenario excludes seeding rate and seed price in the profit calculations (\$ ha^{-1}) reported inside the table.

Lastly, ryegrass cover cropping (treatment 1) was able to control for 90-100% of the broadleaf weeds in the plots. Similarly, treatment 4 controlled 85% (including broadleaves and annual ryegrass), while treatments 5 and 6 controlled 90%.

In summary, using just one early herbicide application allows resistant ryegrass and other existent weeds to grow and spread along the plots. Therefore, only one early herbicide application before soybean establishment negatively affects soybean yield.

Table 10. Sensitivity Analysis for Volunteer Annual Ryegrass Hay Production Terminated with Glyphosate Systemic Herbicide (Optimistic Scenario).

Hay price	**Dry mater production --- kg ha^{-1} ---**					
-- $ kg^{-1}--	**1000.00**	**1500.00**	**2000.00**	**2741.60**	**3000.00**	**3500.00**
$0.100	*($122.03)*	*($72.03)*	*($22.03)*	$52.13	$77.97	$127.97
$0.125	*($97.03)*	*($34.53)*	$27.97	$120.67	$152.97	$215.47
$0.150	*($72.03)*	$2.97	$77.97	$189.21	$227.97	$302.97
$0.175	*($47.03)*	$40.47	$127.97	$257.75	$302.97	$390.47
$0.200	*($22.03)*	$77.97	$177.97	**$326.29**	$377.97	$477.97
$0.225	$2.97	$115.47	$227.97	$394.83	$452.97	$565.47
$0.250	$27.97	$152.97	$277.97	$463.37	$527.97	$652.97
$0.275	$52.97	$190.47	$327.97	$531.91	$602.97	$740.47
$0.300	$77.97	$227.97	$377.97	$600.45	$677.97	$827.97
$0.325	$102.97	$265.47	$427.97	$668.99	$752.97	$915.47
$0.350	$127.97	$302.97	$477.97	$737.53	$827.97	$1,002.97

Note: The optimistic scenario excludes seeding rate and seed price in the profit calculations ($ ha^{-1}) reported inside the table.

Theisen and Bastiaans (2015) demonstrated that annual weeds can prevent soybean seed to be exposed to the soil and germinate when using standard seeders, a situation that can be avoided with modified seeders. In the grazing simulation (treatment 3) the combination of an early forage cut and a late herbicide application allowed for a higher amount of soybean seed germination, better weed management, and therefore resulted in a higher soybean yield.

Irrigation and fertilization were not used in the study; therefore, soybean yields (Table 4) in this study were relatively low. Irrigation is one important factor that influence soybean growth (Mahmoud, Almatboly, and Safina, 2013). In addition, irrigation and fertilization are important for the normal growth of continuously cropped soybean (Cao et al., 2020). Future research may look into incorporating irrigation and fertilization in the study.

Table 11. Sensitivity Analysis for Volunteer Annual Ryegrass Grazing Simulation Terminated with Paraquat Contact Herbicide (Optimistic Scenario).

Grazing rate -- $ kg-1 gain--	Dry mater production ---- kg ha^{-1} ---					
	600.00	**800.00**	**1006.70**	**1200.00**	**1400.00**	**1600.00**
$0.89	$25.27	$54.81	$85.34	$113.89	$143.44	$172.98
$1.00	$36.35	$69.58	$103.93	$136.05	$169.29	$202.52
$1.11	$47.42	$84.35	$122.52	$158.21	$195.14	$232.06
$1.22	$58.50	$99.12	$141.11	$180.37	$220.99	$261.61
$1.33	$69.58	$113.89	**$159.69**	$202.52	$246.84	$291.15
$1.44	$80.66	$128.67	$178.28	$224.68	$272.69	$320.69
$1.56	$91.74	$143.44	$196.87	$246.84	$298.54	$350.23
$1.67	$102.82	$158.21	$215.46	$268.99	$324.39	$379.78
$1.78	$113.89	$172.98	$234.04	$291.15	$350.23	$409.32
$1.89	$124.97	$187.75	$252.63	$313.31	$376.08	$438.86
$2.00	$136.05	$202.52	$271.22	$335.46	$401.93	$468.40

Note: The optimistic scenario excludes seeding rate and seed price in the profit calculations ($ ha^{-1}) reported inside the table.

Similarly, future studies can incorporate stockers, feeder cattle, or beef cows to examine real consumption and analyze variables like ryegrass palatability, grass trampling, and soil compaction. Last, treatments 3 through 6 allow farmers to have a rotation such as wheat-soybean-wheat because all these treatments included an herbicide application or a ryegrass cut that terminates ryegrass and does not allow it to reach the mature seed stage. Eliminating volunteer annual ryegrass during its vegetative or elongation stage reduces the incidence of this plant in the subsequent crop season. In treatments 1 and 2, a rotation corn-soybean-corn will be more suitable because annual ryegrass will reach its seeding stage and wheat stablishing will not be possible because the herbicide used for managing the ryegrass will also affect wheat development (since both plants belong to the family Poaceae).

Conclusions

Cover cropping annual ryegrass (treatment 1) in no-till soybean land offseason had no negative effect on soybean yield, height, and seed density. There were no statistical differences at the 0.05 significance level between the cover crop treatment and the other treatments when conducting multiple mean comparisons. The study suggests there is no detrimental soybean performance when implementing ryegrass cover cropping. In addition, cover cropping is an alternative to reduce herbicide expenses and increase profits. An early application of herbicide in December (treatment 4) obtained a lower yield compared to the grazing simulation (treatment 3), but there was no statistical difference with cover cropping. The results were consistent across the two years evaluated.

Annual ryegrass produced 2,741.60 kg ha^{-1} of dry matter from late fall to late spring and has the potential to generate a profit from about $230 to $244 ha^{-1}, depending on the herbicide price used to terminate ryegrass (glyphosate or paraquat) and if ryegrass is sold as hay at $0.20 kg^{-1}. Since hay production (treatment 2) did not lead to statistical differences in soybean production with respect to the other treatments, annual ryegrass as a dual-purpose crop (forage and cover crop) was found to be the most profitable management practice for North Texas farmers (refer to Tables 5 and 6 versus Table 7).

Last, the ryegrass grazing simulation (treatment 3) indicated that 503.35 kg ha^{-1} of dry matter can be produced from an early ryegrass cut. Assuming that ryegrass has at least 2 cycles and even regrowth before soybean establishment, 1,006.7 kg ha^{-1} of dry matter of ryegrass can be produced in total (over the 2 cycles). A leasing contract of $1.33 per kilogram gain can generate a profit of $63.22 ha^{-1} if leased to graze 226.8-kg calves for a period of 148 days. Bigger animals will have a higher conversion ratio resulting in a lower profit.

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