

ECONOMIC COMPARISON OF COVER CROP USE IN TEXAS HIGH PLAINS COTTON**W.S. Keeling****Texas A&M AgriLife Extension****Lubbock, TX****K.L. Lewis****Texas A&M AgriLife Research****Lubbock, TX****D.M. McCallister****Texas Tech University****Lubbock, TX****J.W. Keeling****Texas A&M AgriLife Research****Lubbock, TX****P.D. Delaune****Texas A&M AgriLife Research****Vernon, TX****J.A. Burke****Texas A&M AgriLife Research****Lubbock, TX****Abstract**

Conservation tillage coupled with winter cover crops may reduce wind erosion in the North America Great Plains. Although farmers recognize the benefits of conservation practices, their decision to use cover crops is often based on the farm's operating budget. In semiarid ecoregions dependent on irrigation for cotton (*Gossypium hirsutum* L.) production and limited groundwater resources, cover crops using stored soil moisture is a major concern. The objective of this research was to quantify the long-term impacts of conservation tillage and cover crop use on C storage, cotton lint yield, and economic returns in monoculture cotton production. Conservation tillage and rye cover were implemented in 1998 and a mixed species cover of rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth), radish (*Raphanus sativus* L.), and winter pea (*Pisum sativum* L.) was seed in 2014 into half of the rye cover crop plots. Soil organic C in the top 15-cm soil depth was increased by combining conservation tillage with winter cover crops. Cotton lint yield was less with no-tillage and the rye cover when compared with conventional tillage in 2 of 3 years. As a result, cotton lint revenue and gross margins of conservation tillage were on average less than conventional tillage.

Introduction

In the semi-arid, High Plains region of Texas, upland cotton (*Gossypium hirsutum* L.) is planted on more acres than all other crops (NASS, 2017). Cotton is vitally important to Texas, which has led the U.S. in production of upland cotton since 1965 with a total of 2.3 million hectares planted, yielding \$2.47 billion to the Texas economy (ERS, 2017; NASS, 2017). Within the Texas High Plains (THP) 1.3 million hectares of cotton were harvested in 2016, more than 60% of Texas total cotton production (NASS, 2017). A majority of this production is dryland which depends on timely rainfall for crop success and generally produces less compared to irrigated systems. Cotton production is a key component of the west Texas economy, but depletion of the Ogallala Aquifer through deficit irrigation might make producers more reliant on conservation management practices such as conservation tillage and cover crops (Baumhardt et al., 2009).

Cotton production on the THP traditionally involves frequent disturbance of the soil surface as producers perform on average 12 to 15 operations prior to cotton harvest (Keeling et al., 1989). With less residue remaining on the soil surface after cotton harvest compared to other crops such as corn (*Zea mays* L.) and grain sorghum (USDA-ERS, 2012), the soil is more exposed to the environment increasing the potential for wind- and water-induced erosion (Zobeck and Van Pelt, 2012). By incorporating greater biomass producing-crops compared to cotton into rotation or as a cover crop, the soil has greater protection from harsh, semi-arid conditions, resulting in increased water storage and microbial diversity (Acosta-Martinez and Cotton, 2017; Sharma et al., 2017). Keeling et al. (1996) evaluated thirteen fall plantings of small grain and forage legume cover crops on the THP and determined rye (*Secale cereale*), wheat (*Triticum aestivum* L.), Austrian winter pea (*Pisum sativum* L.), and hairy vetch (*Vicia villosa* Roth) established

the greatest stands. Under dryland conditions, stands were greatest in wheat and rye plantings compared to legume covers. The authors did not investigate cover crop effects on soil organic C storage, cotton lint yields, and economic returns.

An agricultural system involving cover crops and crop rotations will increase the quantity of residue returned, which may slow or reverse the decline in SOC reported with intensive tillage in semi-arid regions (Peterson et al., 1998). Increased aggregation of soil particles and organic matter resulting from reduced tillage offer protection to SOC, thereby enhancing soil C storage (Six et al., 2000). Schwartz et al. (2015) reported greater SOC storage with decreased tillage intensity in a long-term wheat-fallow rotation on a clay loam soil in Bushland, TX. Wright and Hons (2005a-c) demonstrated that no-till management practices increased soil aggregation, SOC and total N. Although conservation practices can increase SOC, there are inconsistencies demonstrating a slow increase or lack of C storage gains for reduced tillage practices (Baker et al., 2007). In the Texas Rolling Plains, no significant changes in SOC have been observed in the upper 10 cm after seven years of no-tillage with a terminated wheat cover crop in a continuous cotton cropping system (DeLaune et al., 2015).

Zhou et al. (2017) evaluated the economic impacts of tillage and cover crops on cotton production in Tennessee using data from a long-term study (1984-2012). More specifically, the authors aimed to determine profit-maximizing N fertilization rates resulting in the greatest lint yields and profitability of cotton production with and without alternative winter cover crops under conventional tillage (CT) and no-till systems. Results from this study demonstrated net returns for cover crop systems, including hairy vetch, crimson clover (*Trifolium incarnatum* L.), and winter wheat, to be less than no cover under conventional and no-tillage systems (Zhou et al., 2017). Lower N fertilizer rates and costs with legume cover crops were not enough to offset the cost of establishing and terminating the cover crop. In the Texas Rolling Plains, DeLaune et al. (2012) found net returns in continuous cotton systems to be greater for no-till systems (with and without cover crops) compared to conventional tillage systems. Duzy et al. (2016) evaluated the economic impact of tillage, cover crops, and herbicide regimes to control Palmer Amaranth (*Amaranthus palmeri*) in cotton cropping systems in Alabama. They concluded inversion tillage initially yield the greatest returns but was not significantly different from the CT management practices later in the study. Additionally, they reported no differences in economic return between cover crop and fallow treatments.

Adoption of conservation management practices in the THP will depend on economic performance compared to conventional production systems even though ecosystem services of these systems are recognized by producers. Previous profitability studies of conservation management practices on the THP have determined they were a viable alternative to conventional systems (Keeling et al., 1989; Segarra et al., 1991); however, questions of profitability in modern cropping systems with new cotton varieties, increased weed pressure, and greater input costs are being raised. Without modern information, producers cannot make informed decisions. Johnson et al. (2013) conducted an economic evaluation of integrating cotton and beef production on the THP. The authors concluded the adoption of modern higher yielding cotton varieties was more profitable compared to utilizing grazed rye or wheat cover crops; however, they noted when water availability is not adequate, the cotton monoculture system was not as profitable.

Limited information exists in literature prior to the mid-1990s regarding the economic performance and ecosystem services of conservation tillage and cover crop use in cotton on the THP, a major cotton production area. The objective of this research was to quantify the long-term impacts of conservation tillage and cover crop practices on SOC storage, cotton lint yield, and economic returns compared to conventional production practices. This information can be utilized by scientists and cotton producers on the THP to enhance ecosystem services and improve economic profitability of their operations.

Materials and Methods

A field study was conducted from 1998 to 2017 at the Agricultural Complex for Advanced Research and Extension Systems (AG-CARES), a cooperative between the Texas A&M AgriLife Research and Extension Center at Lubbock and the Dawson County Cotton Growers Association, near Lamsa, TX (32° 46' 22", 101° 56' 18"). The average annual precipitation and temperature were 61 mm and 16°C (Fig. 1), respectively. The soil is classified as an Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) with a pH of 7.5 (USDA-NRCS). The Amarillo series, a benchmark soil of the THP, is extensive in western Texas and eastern New Mexico. In this paper, we report the results from 2014 through 2017, years 18 through 20 of the experiment. In 1998, conventional tillage and no-tillage with rye cover were initiated in a randomized complete block design with three replications. In 2014,

eight of the 16-row rye cover crop plots (1-m row spacing and 76.2 m long) were drill-seeded with a mixed species cover of rye, hairy vetch, radish (*Raphanus sativus* L.), and winter pea.

Treatments evaluated in a continuous cotton system from 2014 to 2017 included conventional tillage (CT) winter fallow, rye cover crop with no-tillage (R-NT), and mixed species cover crop with no-tillage (M-NT). Cover crops were seeded (45 kg ha⁻¹) using a no-till drill on 2 December 2014, 4 November 2015 and 12 December 2016 and were chemically terminated on 10 April 2015, 11 March 2016 and 28 March 2016 using glyphosate (2.3 L ha⁻¹). Prior to termination, cover crops were harvested from a 1 m² area and dried to determine herbage mass on a dry matter (DM) basis, N uptake, and C:N ratios. Nitrogen uptake and C:N ratios are reported in part II of this series of papers (Burke et al., 2018, submitted to Agronomy Journal).

Soil samples were collected following cover crop termination each year in early April to a depth of 60 cm from each plot and analyzed for organic C, total N, nitrate-N, Mehlich III extractable macronutrients, pH and electrical conductivity (EC). Composite soil samples from each plot were collected using three, 5.0 cm soil cores separated into depths of 0-15 and 15-60 cm. Samples were combined prior to oven drying at 60°C for seven days, ground using a flail grinder and sieved to pass through a 2 mm mesh screen.

Extractable soil nutrients including P, K, Ca, Mg, and S was extracted using a procedure adapted from Mehlich (1984) and measured using inductively coupled plasma spectroscopy (ICP). Residual soil inorganic nitrate-N (NO₃⁻-N) was analyzed by the Berthelot reaction involving cadmium reduction to nitrite following extraction with 1 N KCl using a 1:5 soil to extraction ratio (5 g soil:25 ml 1 N KCl), followed by analysis using flow injection spectrometry (FIALab 2600, FIALab Instruments Inc., Bellevue, WA). Electrical conductivity and pH of the soil was determined in a 1:2 soil to water slurry using deionized water, with actual determination made using a conductivity electrode and pH probe (Schofield and Taylor, 1955; Rhoades, 1996). A subsample of each composite soil sample was finely ground with a ring-and-puck grinder and analyzed for organic and inorganic C and total N by combustion (Storer, 1984; McGeenhan and Naylor, 1988; Schulte and Hopkins, 1996). Differential heating was used to separate inorganic and organic C; the primary furnace was set at 650°C with a 2 L min⁻¹ O₂ flow rate for organic C, and total N and C were analyzed with the same instrument at 900°C (Rabenhort, 1988; Wang, 1998).

Cotton (DP 1321 B2RF) was planted on 13 May 2015, 24 May 2016 and 12 May 2017 and was mechanically harvested using a four-row John Deere 7445 Cotton Stripper (Moline, Illinois, USA) on 28 October 2015, 22 November 2016 and 15 November 2017. Weights of seed cotton harvested from entire area of each 16-row plot was determined using a purpose-built weigh wagon (West Texas Lee Company, Lubbock, TX, USA). Grab samples of seed cotton were collected after harvest and then ginned to calculate lint turnout and lint yield. Fiber quality was determined using high volume instrument (HVI) analysis at the Texas Tech University Fiber and Biopolymer Research Institute (<http://www.depts.ttu.edu/pss/fbri.php>; Lubbock, TX, USA).

Following cotton harvest each year, rye and mixed covers were planted into standing cotton stalks without tillage. Conventional tillage plots were shredded and tilled with a chisel plow. In March of each year, trifluralin was applied at 0.84 kg a.i. ha⁻¹ and immediately incorporated with a spring-tooth harrow. Beds were then re-formed. Prior to planting, a rod-weeder was used to destroy any weeds and prepare beds for planting. Two to three in-season cultivations were performed as needed to control weeds and establish furrow-dikes in the conventional tillage plots. In the no-till plots, cover crops were terminated with glyphosate at 0.84 kg ai ha⁻¹ in mid-March to early-April. Prowl H₂O was applied at 1.7 kg a.i. ha⁻¹ and incorporated with center-pivot irrigation (19 mm water applied) following cover crop termination. Two applications of glyphosate were applied in-season for all treatments.

Treatments all received the same irrigation and fertilizer applications each year. Total fertilizer applied was 146 kg N ha⁻¹ and 45 kg P₂O₅ ha⁻¹ in each year. In mid-March of each year, 129 kg ha⁻¹ of ammonium polyphosphate was applied. Urea ammonium nitrate (32-0-0) is applied through center-pivot irrigation in three to four separate applications with the first approximately two weeks prior to planting. Irrigation amounts varied each year depending on rainfall. Pre-plant and in-season irrigation totaled 170 mm, 206 mm and 221 mm in 2015, 2016, and 2017, respectively.

Economic budgets were created to analyze the variable costs associated with each management system. Lint revenue was calculated using a loan rate of \$1.15 kg⁻¹ for all crop years to isolate market risk from production risk. Gross revenues are calculated by multiplying the loan rate and crop yield. Total variable costs estimated for each year are subtracted from gross revenue to obtain gross margin, a measure of profitability.

Table 1 illustrates the variable costs for the conservation tillage system. The costs for tillage operations in the continuous cotton system were obtained from the 2016 Texas Agricultural Custom Rates survey for the North region. Conventional tillage production practices for cotton include sandfighting (x2), cultivator (x2), rotary hoe, rodweeding, listing and Treflan incorporation. Total variable costs per acre for this system was \$180 ha⁻¹.

Table 1. Variable costs for conventional tillage practices (\$ ha⁻¹)

Production Practices	Cost (\$ ha ⁻¹)
Sandfighter (2x)	40
Cultivator (2x)	40
Rotary hoe	25
Rodweed	25
Listing	25
Treflan/Incorporation	25
Total	180

Table 2 illustrates the variable costs for the cover crop systems. The seed costs for both rye and the mixed species were obtained from MBS Seed company in Denton, TX. All other associated variable costs were obtained from the 2016 Texas Agricultural Custom rates survey for the North region. Variable costs associated with cover crop systems include seed, drilling, termination and 2,4-D application. Total variable cost per acre for the rye cover system was \$112 ha⁻¹ and \$178 ha⁻¹ for the mixed species cover system. Costs for all cropping systems were constant across all years of this study.

Table 2. Variable costs for no-tillage with rye cover (R-NT) and no-tillage with mixed cover (M-NT) (\$ ha⁻¹)

Production Practice	R-NT	M-NT
	\$ ha ⁻¹	
Seed	30	96
Drilling	37	37
Termination	25	25
2,4 D	20	20
Total	112	178

Statistical Approach

Data was analyzed using Proc Glimmix at a significance level of $P < 0.05$ (lint yield and soil pH, EC, and nutrient concentrations) or $P < 0.1$ (SOC, cover crop herbage mass, and using SAS version 9.3 (SAS Institute Inc., Cary, NC). Treatments of CT, R-NT, and M-NT were treated as fixed effects and replication was treated as a random effect. Means of significant effects were separated using Fisher's protected LSD at $P < 0.05$ or $P < 0.10$.

Results and discussion

Temperature and precipitation

The Texas Southern High Plains is a semi-arid ecoregion with dry, hot summers and mild winters. A majority of the average annual rainfall of 475 mm from April to September of each year (Fig. 1). Periods of intensive rainfall (May 2015) followed by relative drought occurred throughout the study. The dry winters cause cover crops to use stored soil moisture; however, timely rainfall or deficit irrigation can replace soil moisture required for crop establishment. Crop water demands were greatest during cotton production when temperatures and evapotranspiration were greatest.

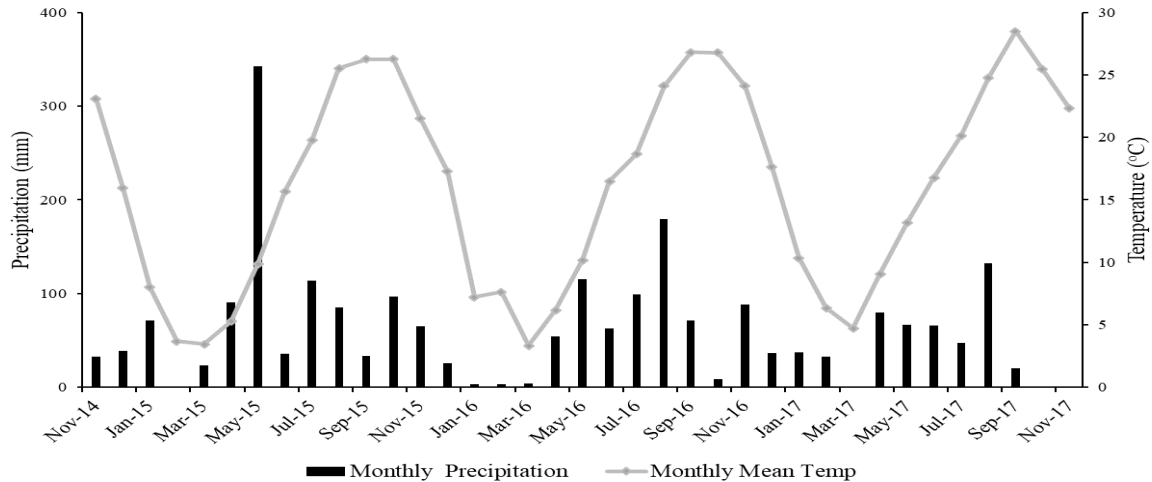


Figure 1. Mean monthly temperature and total monthly precipitation from irrigation and rainfall events at the Agricultural Complex for Advanced Research and Extension Systems (AG-CARES), Lamesa, Texas from 1 November 2014 through 30 November 2017.

Cotton Lint Yield

A year $\times$ treatment interaction was determined for cotton lint yield ($P = 0.05$; Fig. 2); thus treatments are compared within year. Differences between treatments did not exist in 2015 ($P=0.86$), but in 2016 and 2017 differences in lint yield were determined ($P = 0.09$ and $P = 0.04$, respectively; Fig. 2). Cotton lint yield was greater with CT compared to cotton planted into terminated rye cover (R-NT) but not mixed cover (M-NT) in 2016 and 2017. Cotton under CT produced 170 kg ha⁻¹ and 79 kg ha⁻¹ more lint compared to the R-NT and M-NT treatments respectively, in 2016. Differences between conventional tillage and no-tillage treatments were much greater in 2017 with 305 kg ha⁻¹ and 193 kg ha⁻¹ less lint produced with the R-NT and M-NT treatments, respectively, compared to the CT treatment.

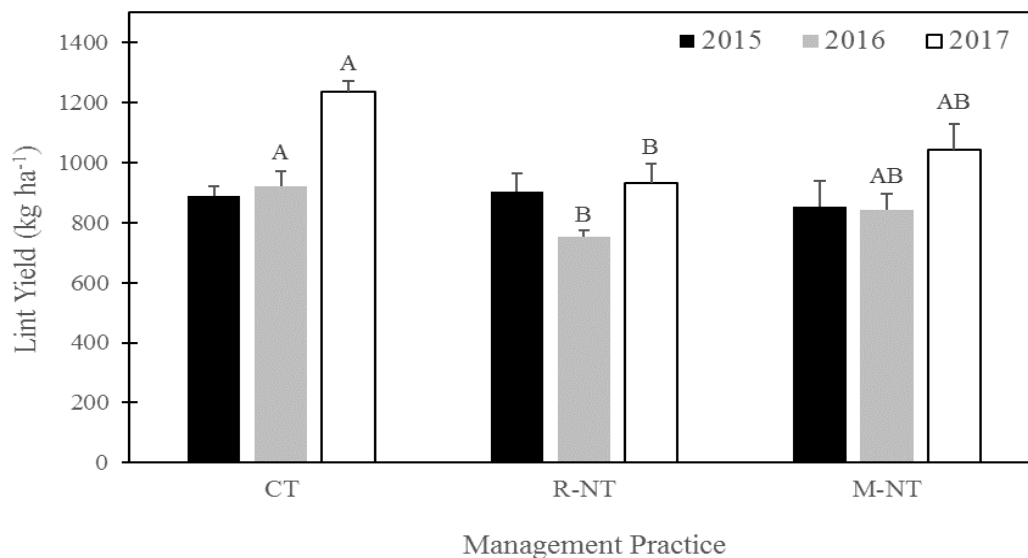


Figure 2. Cotton lint yield in the 2015, 2016, and 2017 growing seasons in Lamesa, TX. Means within year with the same letter are not different at $P < 0.05$. Error bars represent standard error of the sample mean. Conventional tillage, no-tillage with rye cover, and no-tillage with mixed species cover are represented by CT, R-NT, and M-NT, respectively.

These results are not consistent with the few conservation tillage studies conducted in semi-arid regions of Texas (Keeling et al., 1989; Bordovsky et al., 1994; and Baumhardt et al., 2013) and across cotton producing regions of the

U.S. Contradictory to our results, many studies have reported increased cotton lint yield with conservation tillage practices and cover crops (Keeling et al., 1989; Nyakatawa and Reddy, 2000; Boquet et al., 2004; and Hanks and Martin, 2007); however, variability from one year to the next and regionally is common. For example, lint yield differences were not determined between conventional tillage and no-tillage in a four-year study (1986 to 1989) conducted near Halfway, TX (Bordovsky et al., 1994); whereas, in Bushland, TX, a similar ecoregion to Halfway, TX, Baumhardt et al. (2013) reported significantly greater lint yields for cotton produced under no-tillage compared to disk-tillage.

One of the major reasons farmers are reluctant to adopt conservation tillage and cover crop practices is the failure of studies to demonstrate consistent yield and economic benefits over time and across regions. Factors reported to influence the effects of no-tillage coupled with cover crops on cotton lint yield, include: cover crop species (Brown et al., 1985), age of system (Triplett et al., 1996), water availability, and N fertilizer rates (Bronson et al., 2001; Boquet et al., 2004). Contradictory to our findings, Brown et al. (1985) reported no differences of cotton lint yield when using rye cover and no-tillage practices, and reduced yields following vetch and clover cover crops (Fig. 4). After 18-years of using rye cover and no-tillage practices, the age of the system should no longer be causing a yield reduction. Triplett et al. (1996) reported a yield reduction in only the first year of a 4-year study.

A possible explanation for reduced lint yield following rye cover and not the mixed species cover is low N availability resulting from greater N immobilization with the R-NT treatment compared to the M-NT and CT treatments. All treatments received 34 kg ha⁻¹ N as a pre-plant application following cover crop termination with an additional 78 kg ha⁻¹ N applied in-season. Greater N applied throughout the season when using conservation practices has been reported to increase lint yields in semi-arid environments (Bronson et al., 2001). For some farming operations increasing fertilizer input costs may not be possible, but total input costs may be reduced by implementing conservation tillage practices, which requires less machinery and labor costs.

Economics

Input cost, lint revenue, and gross margin are reported for each management system in Table 3. Differences of lint revenue were determined in 2016 and gross margin in 2017; however, similar trends were observed each year. On average, the CT treatment was more profitable than the no-tillage treatments because of greater lint yield and revenue (Fig. 2 and Table 3). In 2015, the year lint yield differences did not exist, management practices had comparable lint revenue and gross margin, but cotton planted into terminated rye cover (R-NT) generated the larger profit of \$924 ha⁻¹ due to less input cost. Conventional tillage without a cover crop outperformed both no-till systems with a gross margin of \$878 and \$1238 ha⁻¹ in 2016 and 2017, respectively. The mixed cover (M-NT) generated \$104 ha⁻¹ more revenue in 2016 and \$129 ha⁻¹ more in 2017 than the rye cover (R-NT) treatment due to increased yield, resulting in a greater gross margin of \$789 and \$1019, respectively. These results appear to be consistent with Zhou et al. (2017). DeLaune et al. (2012) found net returns in continuous cotton systems to be significantly greater for no-till systems (with and without cover crops) compared to conventional tillage systems in the Texas Rolling Plains.

Table 3. Economic comparison between conventional tillage (CT), no-till with rye cover (R-NT) and no-till with mixed cover (M-NT). Means within year with the same letter are not different at $P < 0.1$.

Management Practice	Input Costs [†]	Lint Revenue			Gross Margin		
		2015	2016	2017	2015	2016	2017
-----\$ hectare ⁻¹ -----							
CT	180	1018	1058 a	1418	838	878	1238 a
R-NT	112	1036	863 b	1068	924	751	956 b
M-NT	178	978	967 ab	1197	800	789	1019 ab

[†]No-tillage input costs included: seed, drilling, chemical termination, and in-season herbicide application. Conventional tillage and input costs included: sand fighting (x2), cultivation (x2), rotary hoe, rodweeding, listing and trifluralin herbicide incorporation.

With consistent spring winds and semi-arid environment of the THP, cover crops and conservation tillage can improve ecosystem services by reducing soil erosion and cotton seedling damage while increasing SOC storage and maintaining or possibly enhancing soil quality. Although the benefits of cover crops to cotton lint yield have been documented in this region, our research fails to demonstrate the economic feasibility of using rye and mixed species (rye, hairy vetch, Australian winter field pea, and radish) cover crops with no-tillage due to reduced lint yield. The higher seed prices of the mixed system can be justified as long as it can be offset by higher revenues from increased

yield. Otherwise, it may be too expensive compared to rye, making it the least desirable no-till cover crop option. It is possible that with further investigation to regionally optimize management practices (i.e. fertilizer management and cover crop termination), cover crop use can be an economical practice for cotton production on the High Plains of Texas. However, the benefits will likely be more evident in years with harsher growing conditions.

Summary

With consistent spring winds and the semiarid environment of the THP, cover crops and conservation tillage can improve ecosystem services by reducing soil erosion and cotton seedling damage while increasing SOC storage and maintaining or possibly enhancing soil quality. Although the benefits of cover crops to cotton lint yield have been documented in this region, our research fails to demonstrate the economic feasibility of using rye and mixed species (rye, hairy vetch, Australian field winter pea, and radish) cover crops with no-tillage due to reduced lint yield. The higher seed prices of the mixed system can be justified as long as it can be offset by higher revenues from increased yield. Otherwise, it may be too expensive compared with rye, making it the least desirable no-till cover crop option. It is possible that with further investigation to regionally optimize management practices (i.e. fertilizer management and cover crop termination) cover crop use can be an economically feasible practice for cotton production on the High Plains of Texas. However, the benefits will likely be more evident in years with harsher growing conditions.

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