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Economic analysis of adopting no-till and cover crops in irrigated cotton production under risk

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Abstract

Adoption of soil conservation practices has been promoted to improve environmental and economic benefits across the United States. These practices are especially necessary for soil health improvement in the Southern High Plains where soils are prone to erosion and agricultural irrigation relies heavily on groundwater. Winter cover crops and no-till cropping are two conservation practices for reducing soil erosion, but producers might face additional risks associated with adopting these practices. The objective of this study was to examine the profitability and risks associated with alternative tillage and cover crops (no cover crop, winter wheat [*Triticum asestivum* L.], and grass–legume mixture) for irrigated cotton (*Gossypium hirsutum* L.). Using data from a 6-yr field experiment, net return distributions of each production system were evaluated and ranked across various risk aversion levels. The results showed that the average net returns were \$1040 and \$1049 ha^{-1} for conventionally tilled and no-till cotton without a cover crop, while the net returns were \$1121 and \$1075 ha^{-1} for no-till cotton with wheat and mixed cover crops, respectively. Producers adopting cover crops had a greater probability of getting a middle interval of net returns between \$760 and \$1370 ha^{-1}. The results of risk analysis show that risk-neutral and slightly risk-averse producers prefer no-till cotton production with wheat cover, while no-till with mixed and wheat cover are the first and second most preferred systems for very and extremely risk-averse producers. Sensitivity analysis confirms consistent profit effects of cover crops and no-till adoption at multiple cotton price levels.

1 | INTRODUCTION

Risk is an intrinsic component in producers' decision-making process due to the variability and uncertainty of agricultural production (Boyer, Roberts, Larson, McClure, & Tyler, 2015; Larson, Jaenicke, Roberts, & Tyler, 2001; Moschini & Hennessy, 2001). The economic consequences of producers' actions are highly influenced by the uncertainty in weather conditions, prices, and biophysical factors (Wade, Claassen, & Wallander, 2015). These factors largely result in the difficulties in predicting yield and income of different farming practices (Lien, Brian Hardaker, & Flaten, 2007). Uncertainty has been argued as a key barrier to the wide adoption of conservation practices largely because it hinders the fulfilment of agricultural activities (Lee & McCann, 2019; Singer, Nusser, & Alf, 2007; Wade et al., 2015). To motivate farmers to adopt conservation practices, the perceived uncertainty needs to be

Abbreviations: ARAC, absolute risk-aversion coefficient; CE, certainty equivalent; CPI, consumer price index; CT, conventional tillage; NT, no-till; RP, risk premium; RRAC, relative risk-aversion coefficient; SERF, stochastic efficiency with respect to a function.

outweighed by the expected gains (Bergtold, Duffy, Hite, & Raper, 2012). A comparative evaluation of the potential gains from adopting conservation practices, such as no-till (NT) and cover crops, can better help producers make informed farm management decisions (Prokopy et al., 2019).

The advantages of adopting NT and cover crops include retaining crop residues on the soil surface, increasing soil organic matter and nutrients, improving water holding capacity, reducing water evaporation, and mitigating soil erosion (Cates & Jackson, 2018; Dabney, Delgado, & Reeves, 2001; Daryanto, Fu, Wang, Jacinthe, & Zhao, 2018; Snapp et al., 2005; Triplett & Dick, 2008). Studies have reviewed the adoption of NT in the United States (Prokopy et al., 2019; Ranjan, Church, Floress, & Prokopy, 2019) and concluded that NT resulted in improvements in soil properties, greater cropping intensity, and higher crop productivity (Hansen, Allen, Baumhardt, & Lyon, 2012; Wallace et al., 2017). Agronomic and economic influences of cover crop adoption have been evaluated in studies of different cropping systems (Lewis et al., 2018; Schomberg et al., 2014; Zhou, Larson, Boyer, Roberts, & Tyler, 2017). The outcomes of these studies varied across regions and were affected by other farm practices, such as fertilizer application and crop rotation (Marcillo & Miguez, 2017; Miguez & Bollero, 2005; Ranjan et al., 2019).

Texas is the leading state in cotton (*Gossypium hirsutum* L.) production in the United States with 3.14 million hectares planted and $2.38 billion production value in 2018 (USDA-ERS, 2018; USDA-NASS, 2019a). Texas Rolling Plains is a semi-arid region, located in the north-central Texas. This region consists of 22 counties and borders Oklahoma to the north. The annual precipitation in this region ranges from 460 mm in the west to 760 mm in the east, and most precipitation occurs during May–September (Adhikari et al., 2017). Both dryland and irrigated cotton systems are widely practiced in this region (USDA-ERS, 2018). A major source of irrigation water is the Seymour Aquifer, and about 90% of the groundwater is used for agriculture. The center-pivot sprinkler system is the most common irrigation method.

However, limited research has evaluated the economic benefits and producers' risk preference for alternative tillage and cover crop systems for irrigated cotton production in Texas (Prokopy et al., 2019). Varner, Epplin, and Strickland (2011) compared the profitability of NT and conventional tillage (CT) for cotton, grain sorghum (*Sorghum bicolor* L.), and wheat (*Triticum asestivum* L.) in Southwest Oklahoma, and they concluded that the net returns were slightly greater for NT than CT for wheat, while there was no difference for the other cropping systems. Lewis et al. (2018) evaluated the impact of conservation tillage and cover crops used in cotton production in north Texas, and found that cotton lint revenue and gross margins of CT were greater than conservation tillage. Based on a long-term cotton experiment with various winter cover crops (wheat, hairy vetch [*Vicia villosa* L.], and crimson clover [*Trifolium incarnatum* L.]) and tillage treatments (till vs. NT) in Tennessee, Zhou et al. (2017) found that the net returns were greater for NT cotton production using hairy vetch, followed by NT with crimson clover.

Core Ideas

- Cover crops increased the probability of positive net returns with an interval of $760–1370 ha^{-1}.
- No-till treatments outweighed conventional tillage in terms of certainty equivalent, regardless of risk aversion levels.
- Risk-neutral and slightly risk-averse producers would prefer adopting no-till with wheat cover crop.
- Very and extremely risk-averse producers would prefer adopting no-till with mixed cover crops.

Producers are risk-averse with different levels of risk aversion (Lien et al., 2007) and have different preferences for tillage and cover crops (Carlisle, 2016). Evaluation of farm income at varying risk-aversion levels for NT and cover crops adoption has been conducted on different cropping systems in the United States. (Williams, Johnson, & Gwin, 1987; Williams, Llewelyn, & Mikesell, 1989; Yiridoe, Weersink, Swanton, & Roy, 1994). Stochastic efficiency with respect to a function (SERF; Hardaker, Richardson, Lien, & Schumann, 2004) has been used to conduct economic risk analysis of various cropping systems (Lien et al., 2007; Richardson, Schumann, & Feldman, 2008; Williams et al., 2012). Using SERF, Williams et al. (2012) assessed the economic feasibility of conservation tillage and winter wheat for corn (*Zea mays*), sorghum, and soybean (*Glycine max*) in south-central Kansas. They concluded that NT and reduced-till wheat–soybeans systems were the first and second most preferred systems across multiple risk aversion levels. Similarly, Boyer, Lambert, Larson, and Tyler (2018) investigated the profitability and net return distributions of cover crops (no cover crop, winter wheat, and hairy vetch) and tillage (CT and NT) treatments in Tennessee cotton production. Their long-term analysis showed that risk-neutral producers preferred CT without a cover crop, while risk-averse producers preferred NT without a cover crop.

This study conducted an economic risk analysis to evaluate the profitability of alternative tillage and cover crops in irrigated cotton production in Texas. A 6-yr field experiment was conducted from 2013 to 2018 in the Texas Rolling Plains. Irrigated cotton was grown continuously in annual rotation with CT without a cover crop, NT without a cover crop, and NT with cover crops. The cover crop treatments include winter wheat and grass–legume mixture. A partial budget approach was used to calculate the real net returns for each production system. The distributions of the net returns were compared using a SERF procedure. This procedure ranks risky alternatives associated with the adoption of different tillage and cover crop practices at various risk aversion levels of cotton producers.

2 | MATERIAL AND METHODS

2.1 | Experimental design and data

Data from field experiments have been widely used to conduct economic analysis on alternative conservation practices (Boyer et al., 2018; Cochran, Roberts, Larson, & Tyler, 2007; Ott & Hargrove, 1989). In this study, a field experiment was conducted at Texas A&M AgriLife Research Station at Chillicothe, Texas (34°15′11.40″ N, 99°30′26.39″ W) from 2013 to 2018 (DeLaune, Mubvumba, Fan, & Bevers, 2020). Continuous cotton under irrigation was grown on a Rowena clay loam soil. Four replications were established in a randomized block design and treatments included: (i) conventional tillage without a cover crop (CT_None), (ii) no-till without a cover crop (NT_None), (iii) no-till with winter wheat (NT_Wheat), and (iv) no-till with legume–grass mixture (NT_Mix). The seeding rate for wheat cover crop was 33.63 kg ha^{-1}. The mixed cover crops included rye (*Secale cereal* L.), wheat, vetch, clover, pea (*Pisum sativum* L.), radish (*Raphanus raphanistrum* ssp. *sativus* L.), and turnip (*Brassica rapa* ssp. *rapa* L.). The total seeding rate was 44.83 kg ha^{-1} in 2013, and 33.63 kg ha^{-1} in 2014–2018. The cover mixture and proportion of each species varied each year. The same tillage and cover crop treatments were applied consistently to each plot each year.

Cover crops were planted in October–November of the previous year and chemically terminated in April before planting cotton. Griffin and Barnes (2017) reported the most active planting dates for cotton production in 13 states, while data for Texas were not available from the United States Department of Agriculture (USDA) at the time of publication. Cotton seeds were planted using a mechanical planter at 1-m row spacing in early June. Plots for the irrigated system were 18 by 8 m in size. Conventional plowing and bedding were practiced for CT in each spring. A chemical herbicide, N fertilizer, and growth regulator were applied equally for all the plots each year. Cotton plants were sprayed with defoliant 1–2 wk before harvesting each year. A mechanical harvester was used to harvest seed cotton, and samples were ginned to obtain lint yield. Irrigation water was applied to meet 85% evapotranspiration replacement and equally applied to all the plots using a center-pivot sprinkler system (Adhikari et al., 2017). The amount of irrigation water varied for each year depending on the precipitation and plant water demand.

2.2 | Net return

This study used yield and inputs data from a 6-yr cotton experiment to estimate the net return for irrigated cotton. Specifically, lint yield was obtained from the field trial for each plot and each treatment after ginning of seed cotton. The cottonseed yield was estimated using a conversion ratio of 1.412 units of seed/unit of lint (Cotton Incorporated, 2018). The gross revenue in nominal values was calculated for each replicate $i (i = 1, \ldots, 4)$ and each tillage and cover crop treatment $j (j = 1, \ldots, 4)$ in each production season $t (t = 2013, \ldots, 2018)$. Historical prices of cotton lint and cottonseed in Texas for each year were used in the calculation of gross revenue according to the following (USDA-NASS, 2019b):

$$\text{Gross revenue}_{ijt} = \left(\text{Lint price}_t\right)\left(\text{Lint yield}_{ijt}\right) + \left(\text{Seed price}_t\right)\left(\text{Seed yield}_{ijt}\right) \quad (1)$$

To compare gross revenue across 6 years, nominal values were adjusted to real gross revenue in the 2018 US dollars using Consumer Price Index (CPI; Bureau of Labor Statistics, 2019).

$$\text{Real gross revenue}_{ijt} = \left(\frac{\text{CPI}_{2018}}{\text{CPI}_t}\right)\text{Nominal gross return}_{ijt}, \quad t = 2013, \ldots, 2018 \quad (2)$$

Total cost was calculated considering all the inputs and farm management practices during the production season. The total cost for each plot i of treatment j in each year t was calculated as:

$$\text{Total cost}_{ijt} = \text{Variable cost}_{ijt} + \text{Fixed cost}_{ijt} \quad (3)$$

These costs were estimated using an enterprise budget developed by Texas A&M AgriLife Extension economists (Texas A&M AgriLife Extension, 2019). Estimations for the Rolling Plains Extension District 3 were used, but with modification for cotton lint and seed prices, expenses on cover crops and tillage operations, and other variable inputs. Variable costs included expenses on cover crop seed, cotton seed, N fertilizer, energy use for irrigation, chemicals, fuel, lubricants, repairs and maintenance, labor, custom application relating to chemicals, fertilizer and irrigation, interest, and harvesting (insurance and land rental were not included). Fixed costs included depreciation of machinery for planting cover crops and cotton, plowing and bedding (for CT), irrigating, spraying chemicals, etc. Starting from termination of cover crops, irrigation and applications of herbicides, growth regulator, and defoliant were the same for all the plots during the production season each year.

The net return per hectare of irrigated cotton was calculated as:

$$\text{Net return}_{ijt} = \text{Real gross revenue}_{ijt} - \text{Total cost}_{ijt} \quad (4)$$

Analysis of variance (ANOVA) was conducted using SAS Version 9.4 (SAS Institute, 2014). We compared differences in the mean values of total costs, lint yields, and net returns of the tillage and cover crop treatments. Fisher's protected Least Significant Difference (LSD) was used and treatments were determined significantly different at the .05 probability level ($P \leq .05$).

2.3 | Risk aversion

The uncertainty related to inputs and crop yield with adopting conservation practices could result in income variation. Farmers' decision-making process is affected by the expected revenue while subject to their risk attitudes (Richardson, Klose, & Gray, 2000). Producers may hold differing attitudes toward risks, and thus they may have different preferences for NT and cover crop choices (Boyer et al., 2018; Larson et al., 2001). Those who are more risk-averse are more likely to choose the farm practices that have a smaller variation in farm income (Liu, Langemeier, Small, Joseph, & Fry, 2017). This research compares mutually exclusive production decisions by cotton producers for adopting NT and winter cover crops.

Producers' risk attitudes are measured by a range of absolute risk aversion coefficients (ARAC; r_a) as specified by Anderson and Dillon (1992). According to Hardaker et al. (2004), the absolute risk aversion coefficient is computed by:

$$r_a(w) = \frac{r_r(w)}{w} \quad (5)$$

where $r_r(w)$ is the relative risk-aversion coefficient (RRAC) for a certain amount of income. The Arrow–Pratt measure of ARAC (Pratt, 1964) is defined as $r_a = -u''(w)/u'(w)$, which represents the ratio of the derivatives of the decision maker's utility function, $u(w)$. According to Anderson and Hardaker (2003), relative risk-aversion levels used in this analysis included risk-neutral ($r_r(w) = 0$), somewhat risk-averse ($r_r(w) = 1$), rather risk-averse ($r_r(w) = 2$), very risk-averse ($r_r(w) = 3$), and extremely risk-averse ($r_r(w) = 4$). w is equal to \$1071 ha^{-1} which is the average value of net returns of irrigated cotton production in all the tillage and cover crop treatments. Thus, the ARAC used in this study included 0 for risk-neutral, .0009 for somewhat risk-averse, .0019 for rather risk-averse, .0028 for very risk-averse, and .0037 for extremely risk-averse. This study considered farmers' attitude changing from risk-neutral to extremely risk-averse and evaluated the risk effects on farm income.

2.4 | Stochastic efficiency with respect to a function

According to Hardaker et al. (2004), the SERF procedure ranks a set of risky alternatives based on their certainty equivalents (CEs) for a specific range of risk aversion levels. The CE of a risky alternative is the guaranteed amount of money at which a decision maker would be willing to accept, instead of taking the risky alternative. The CE for a risky alternative is determined by the utility function and the risk aversion levels of the decision maker, that is, $CE(w, r(w)) = U^{-1}(w, r(w))$ (Lien et al., 2007). The risky outcome with a higher CE value should be preferred over those with lower CE values (Liu et al., 2017). Specifically, at a certain risk-aversion level, the decision maker will choose the risky alternative that provides the highest CE. Compared to using utility values, CE values are easier to interpret and often preferred in empirical research (Hardaker et al., 2004).

Estimating CE values requires a specific form of utility function. Schumann, Richardson, Lien, and Hardaker (2004) compared six utility functions and concluded that the efficient sets were similar across different utility functions. In this risk analysis, a negative exponential utility function was used to represent risk-averting behavior in the SERF analysis (Babcock, Choi, & Feinerman, 1993; Schumann et al., 2004; Williams, Saffert, Barnaby, Llewelyn, & Langemeier, 2014). This utility function conforms to the hypothesis of risk-averse decision makers, that is, the decision makers prefer less risk to more, given the same expected return (Anderson & Dillon, 1992). Another assumption for this functional form is that decision makers have constant absolute risk aversion (Williams et al., 2012).

A utility weighted risk premium (RP) was calculated using Equation 6 at a certain absolute risk aversion level. The RP measures the difference in CEs between adopting NT with or without cover crops and conventional tillage.

$$\text{RP}_{\text{NT,CT},r_a} = \text{CE}_{\text{NT},r_a(w)} - \text{CE}_{\text{CT},r_a(w)} \quad (6)$$

The value of RP represents the minimum amount of money (\$ha^{-1}) that a decision maker will have to receive before they are willing to switch from NT with or without cover crops to CT under a specific absolute risk aversion level $r_a(w)$. In this study, a positive RP indicates the cotton producers would prefer NT with or without a cover crop to the CT, and the positive value of RP could also be viewed as the risk adjusted gain from adopting NT with or without a cover crop. In contrast, a negative RP means that the cotton producer prefers CT over NT with or without a cover crop, and the negative value of RP could be viewed as the expected loss or the amount of compensation for farmers to adopt NT with or without a cover crop.

The risk analysis was conducted using the Simulation and Econometrics to Analyze Risk (SIMETAR) software developed by Richardson et al. (2008). The SERF analysis was conducted for the net return distributions of cotton production in each of the tillage and cover crop treatments. Risk premiums and their rankings are reported in the analysis for a range of ARACs from risk-neutral to extremely risk-averse. Producers with ARACs equal to zero are risk-neutral, whereas those with ARACs greater than zero are risk-averse.

3 | RESTULTS AND DISCUSSION

3.1 | Production cost

Table 1 presents the production costs of the four tillage and cover crop treatments. The total costs for no-till with wheat and mixed cover crops (\$1463 ha^{-1} and \$1508 ha^{-1}, respectively) were greater than that of no-till without a cover crop (\$1362 ha^{-1}), while no difference was observed between wheat cover crop and conventional tillage (\$1398 ha^{-1}). The differences in total costs were mainly attributed to the higher seed costs and harvesting costs in the cover crop treatments. The conventional tillage had higher costs of fuel and labor. This indicates that cost savings on no-till may promote growers to use more conservation tillage, while an increase in production cost may be a barrier for cover crop adoption (Prokopy et al., 2019; Ranjan et al., 2019).

TABLE 1 Production cost (\$ ha^{-1}) of irrigated cotton production (2013–2018) under conventional tillage (CT) and no-till (NT) without a cover crop (None) and with winter wheat (Wheat) and mixed cover crops (Mix). Number of observations for each treatment is 24

	CT_None	NT_None	NT_Wheat	NT_Mix
Cost items	\$ ha^{-1}			
Seed[a]	135	135	155	197
Fertilizer	69	69	69	69
Chemical	94	94	94	94
Irrigation	112	112	112	112
Labor	19	13	17	17
Fuel	39	19	27	27
Lube, repair and maintenance	18	17	19	19
Custom application	90	90	90	90
Interest	11	11	12	15
Harvest cost	673	662	723	724
Machinery depreciation	137	140	144	144
Total cost[b]	1398bc	1362c	1463ab	1508a

[a]Seed costs include costs for both cotton and cover crop seeds in the cover crops treatments.

[b]Different letters following the total costs indicate significant differences between two treatments by Fisher's LSD test at $P \leq .05$.

3.2 | Yield and net return

The summary statistics of cotton lint from adopting different tillage methods and cover crops are provided in Table 2. No significant difference in lint yields was found between the treatments (P = .2207). Compared to the average lint yield of 1323 kg ha^{-1} for CT, NT without a cover crop had a similar average yield level of 1300 kg ha^{-1}, while NT with wheat and mixed cover crops increased average lint yield to 1422 and 1424 kg ha^{-1}, respectively. The coefficient of variation showed NT without a cover crop and with cover mixture had a slightly smaller variation in lint yield compared to the other two treatments. Our findings are consistent with previous studies of field experiments on cotton production. For example, Cochran et al. (2007) reported NT increased cotton lint yields. Jaenicke, Frechette, and Larson (2003) found that wheat cover crops resulted in a larger yield variation than using clover or vetch. Boyer et al. (2018) also pointed out that the effect may depend on cover crop species and the amount of additional fertilizer applied.

The net return per hectare for cotton production practicing different tillage and cover crops is shown in Figure 1. Overall, the average net returns of different treatments were similar. Compared to the average net return of \$1040 ha^{-1} for CT, NT without a cover crop had an average net return of \$1049 ha^{-1}. No-till with wheat and mixed cover crops increased average lint yield to \$1121 ha^{-1} and \$1075 ha^{-1}, respectively. Though adding cover crops increased the production costs in terms of seed cost and operation expenses related to planting and terminating cover crops, a slight increase in yield mentioned above partially offset the increased costs. As a result, the numeric values of net return were higher for the cover crop treatments. As indicated by the coefficient of variation, the net returns of NT with wheat and mixed cover crops exhibited

TABLE 2 Summary statistics of lint yield (kg ha^{-1}; data from DeLaune et al., 2020) of irrigated cotton production (2013–2018) under conventional tillage (CT) and no-till (NT) without a cover crop (None) and with winter wheat (Wheat) and mixed cover crops (Mix). Number of observations for each treatment is 24

	Mean[a]	SD[b]	CV	Min	Max
Treatments	kg ha^{-1}		%	kg ha^{-1}	
CT_None	1323	267	20.15	817	1804
NT_None	1300	240	18.42	977	1831
NT_Wheat	1422	271	19.05	837	1884
NT_Mix	1424	266	18.70	867	2054

[a]Significant differences were not determined by Fisher's LSD test (P = .2207).

[b]SD, standard deviation; CV, coefficient of variation.

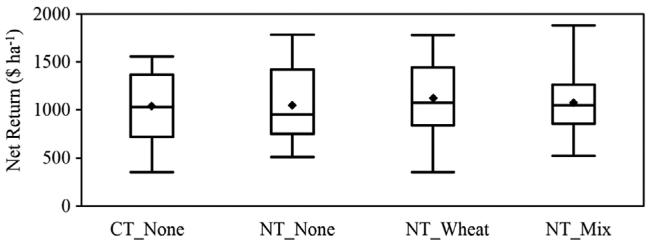

FIGURE 1 Box plots of net returns (\$ ha^{-1}) for irrigated cotton production under conventional tillage (CT) and no-till (NT) without a cover crop (None), with winter wheat (Wheat) and mixed cover crops (Mix). Number of observations for each treatment is 24. Box plots are a graphical summary of the data distribution. The horizontal line within the box represents the median value, and the dot within the box represents the mean value. The lower and upper ends of the box represent the 25th and 75th quantiles, respectively. Whiskers that extend from the ends of the box are the maximum and minimum values of the distribution. Significant differences across the treatments were not determined by Fisher's Least Significant Difference test ($P = .8551$). The coefficient of variation (CV) were 33.09, 35.80, 32.84, and 29.62 for CT_None, NT_None, NT_Wheat, and NT_Mix, respectively

a smaller variability compared to no cover crop treatments (Figure 1). Compared to the above results of lint yields, this indicates that cover crops help reduce the risk in income variability. Our finding also suggests the effects of NT may vary, depending on the cropping systems or other farm practices (Fox, Weersink, Sarwar, Duff, & Deen, 1991; Marcillo & Miguez, 2017; Prokopy et al., 2019).

3.3 | Stoplight chart analysis

Stoplight chart analysis was conducted to graphically illustrate the net return distributions of tillage and cover crop treatments. Figure 2 shows the probabilities of cotton net return per hectare being less than \$760 and greater than \$1370 for different tillage and cover crops practices. The lower and upper cut-off values were determined using the average net return of all the treatments at the 25 and 75 percent quantiles (Richardson, 2010).

An overall comparison of the four scenarios showed that NT with or without a cover crop practices can generate a higher probability of getting a larger net return than CT. The results showed that NT with wheat and mixed cover crops can reduce downside risk by reducing the probability of getting lower net returns, compared to CT. No-till without a cover crop showed a similar level of downside risk with the probabilities of getting lower net returns. But NT without a cover crop increased the probability of getting a higher net return compared to CT.

For both CT and NT without a cover crop, the probability of the average net return less than \$760 ha^{-1} was .33. Meanwhile, the probabilities of the net return less than \$760 ha^{-1} were .17 and .13 for NT with wheat and cover crop mixture, respectively. Among all four treatments, the probability of net return exceeding \$1370 ha^{-1} was greatest for NT without a cover crop and with wheat cover (.29). For the middle interval between \$760 ha^{-1} and \$1370 ha^{-1}, NT with cover mixture (.71) had the greatest probability, followed by NT with wheat (.54).

3.4 | SERF results

We used SERF to rank the tillage and cover crop treatments based on CEs (Figure 3). The risk aversion level goes from risk-neutral (ARAC = 0) to extremely risk-averse (ARAC = .0037). The locus of points with the highest CE values are the most risk preferred tillage and cover crop treatment by cotton producers.

All NT planting treatments outperformed the CT treatments, regardless of risk aversion levels. This suggests NT should be preferred by cotton producers, and specific adoption of cover crops depends on the risk aversion level. The CE distributions for NT with wheat and NT with mixed cover crop appear at the top of the graph. These two distributions cross each other when ARAC equals .0023. For those cotton producers with ARAC between 0 and .0023, NT with wheat was their most preferred risk mitigating tillage and cover crop practice. For more risk-averse cotton producers with ARAC higher than .0023, they would prefer NT with mixed cover

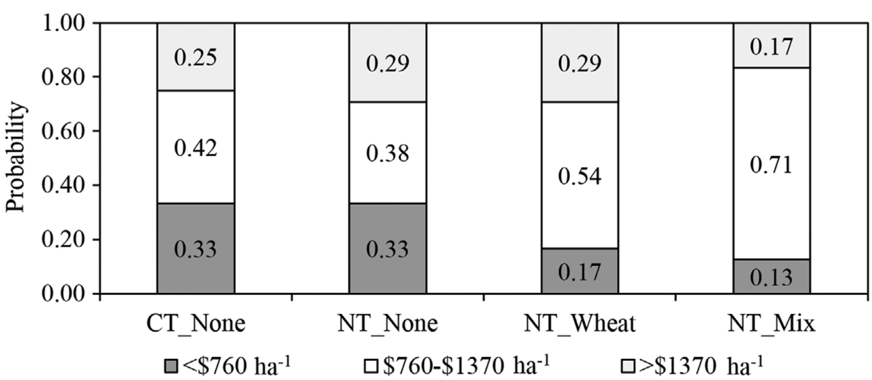

FIGURE 2 Stoplight charts for probabilities less than \$760 and greater than \$1370 per hectare. CT, conventional tillage; NT, no-till. Number of observations for each treatment is 24

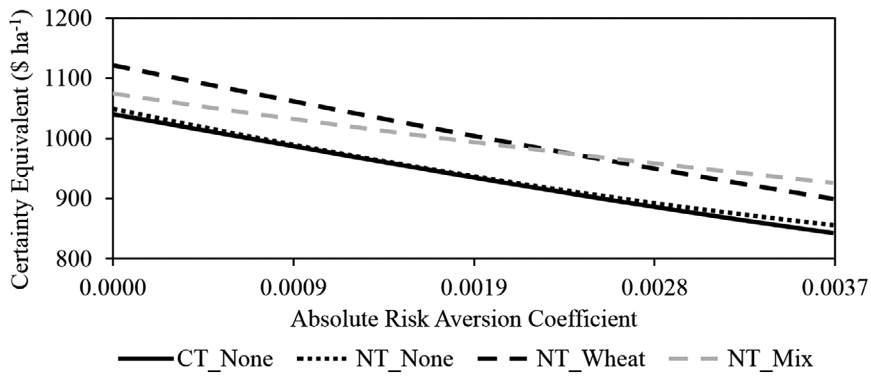

FIGURE 3 Certainty equivalents ($ ha^{-1}) of the tillage and cover crop treatments for irrigated cotton production. CT, conventional tillage; NT, no-till; None, without a cover crop; Wheat, with winter wheat; with mixed cover crops

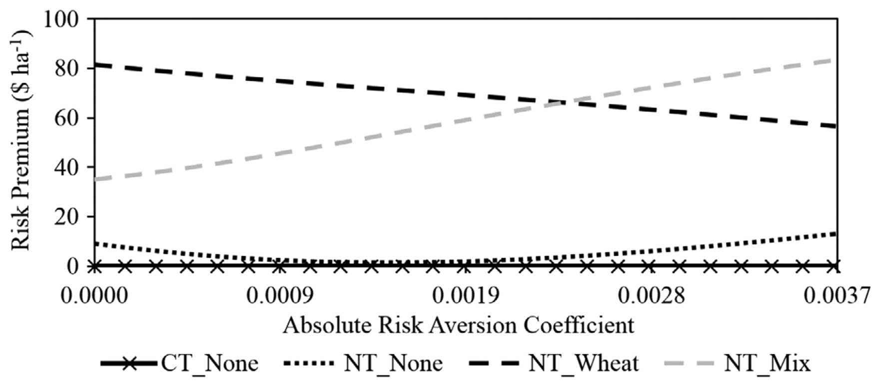

FIGURE 4 Risk premiums ($ ha^{-1}) of the tillage and cover crop treatments for irrigated cotton production (Base treatment is CT_None). CT, conventional tillage; NT, no-till; None, without cover crops; Wheat, with winter wheat; Mix, with mixed cover crops

crop. Therefore, wheat is more likely to be adopted by neutral, slightly, or moderately risk-averse producers and the use of mixed cover crops is more likely adopted by highly risk-averse producers.

While irrigation water was applied to meet 85% of water demand in this study, our risk analysis results may be different from others conducted in dryland conditions. Although acknowledging that NT could reduce dryland cotton growers' exposure to risk, Boyer et al. (2018) and Harmon, Boyer, Lambert, Larson, and Tyler (2018) found that risk-averse producers preferred NT while risk-neutral producers preferred CT. Other studies also observed a better economic potential of adopting cover crops by producers with moderate or very risk-averse attitudes (Larson et al., 2001; Yiridoe et al., 1994). This suggests that the biophysical benefits associated with NT and cover crops might take a long period of continuous use before they can realize any economic advantage, which is consistent with the conclusion of Soule, Tegene, and Wiebe (2000). Findings by Allen and Borchers (2016) also confirmed that yield variability or production risk may be reduced by practicing NT.

To find the risk-adjusted value of NT with or without a cover crop, SERF analysis calculated the RPs relative to CT (Figure 4). Risk Premium presents the minimum amount of payment that a cotton producer has to be paid before they are willing to switch from NT to CT. The RP values are plotted across various risk-aversion levels changing from risk-neutral to extremely risk-averse. The positive RP value could be viewed as the value created to cotton producers by adopting NT and cover crops.

TABLE 3 Risk premiums of net returns ($ ha^{-1}) of tillage and cover crop treatments in irrigated cotton production. (Base treatment is CT_None)

Risk aversion level	ARAC[a]	NT_None	NT_Wheat	NT_Mix
		$ ha^{-1}		
Risk neutral	.0000	9	82	35
Somewhat risk averse	.0009	2	75	46
Rather risk averse	.0019	2	69	59
Very risk averse	.0028	6	63	72
Extremely risk averse	.0037	13	57	83

[a]ARAC, absolute risk aversion coefficient; CT, conventional tillage; NT, no-till.

The numeric value of RPs of different tillage and cover crop practices are presented in Table 3 (the corresponding CEs are shown in Supplemental Table S1). Compared to CT, all the RPs were positive across various risk-aversion levels. This suggests that cotton growers at various risk aversion levels would need to receive some minimum level of payment to justify a switch from NT and cover crops to CT. Our results are consistent with Archer and Reicosky (2009) and Williams et al. (2012) who concluded that NT was preferred by both risk-neutral and risk-averse farmers. Larson et al. (2001) also observed that adopting hairy vetch was more risk efficient for risk-averse cotton producers who had already practiced NT.

4 | SENSITIVITY ANALYSIS

We examined the changes in cotton price on the net return of irrigated cotton. Five price levels (average prices, ±20%, and ±40%) of cotton lint and cottonseed were examined in the sensitivity analysis (the prices are shown in Supplemental Table S2). The average prices of lint and cottonseed were obtained from the US Department of Agriculture National Agricultural Statistics Service (USDA-NASS, 2019b). The price level equal to "average price−40%" is very close to the breakeven price which is approximately "average price−42%."

4.1 | Price impact on net return

Figure 5 depicts the distribution changes of net returns using wheat cover crop at various price levels as an example. The net returns related to all tillage and cover crop treatments at each price level are provided in Supplemental Figure S1. Figure 5 shows, compared to the average price level, a higher or lower price increases or decreases net return of irrigated cotton production while the variability of net return is also increased or decreased simultaneously. A 20% price change approximately changes the average net return of \$505 ha^{-1} in the wheat cover scenario, which is a 47% change in net return at the average price level. Additionally, the probability density function distributions for wheat and mixed cover crops move further to the right, indicating that a higher price makes the outcomes of adopting wheat and mixed cover crops more promising. Therefore, growers may be more likely to adopt cover crops with higher lint and seed prices.

4.2 | Price impact on risk premium

Figure 6 shows the changes of risk premium at various price levels. The alternative stochastic efficiency results for various price levels are provided in Supplemental Figure S2. As an example, Figure 6 compares the RPs of the wheat treatment to the CT across various risk-aversion levels. Compared to CT without a cover crop, NT with wheat cover has a positive RP at different price levels and across various risk-aversion levels. At a higher price level, the RP adjusts more substantially as a cotton producer' risk-aversion level moves from neutral to extremely averse. For instance, at the average price level, the RP changes from \$82 ha^{-1} at ARAC = 0 to \$57 ha^{-1} at ARAC = .0037, that is, an adjustment of \$25 ha^{-1}. While at the +40% price level, the RP changes from \$153 ha^{-1} at ARAC = 0 to \$90 ha^{-1} at ARAC = .0037, which is an adjustment of \$63 ha^{-1}. Furthermore, the CEs and RPs at various price levels show a dynamic change of all tillage and cover crop treatments (Supplemental Figure S2). A comparison across the price levels shows that the wheat and mixed cover crops are more favorable at a higher price level. No-till with wheat cover ranks first at all the price levels except for the very low price, that is, –40%, when a producer is risk-neutral or slightly risk-averse. If a producer is more risk-averse, the dominant RP will switch from wheat to mixed cover crops as the price becomes higher. For any higher than average price levels, a grouping of wheat (when the risk aversion level is low) and mixed cover crops (when the risk aversion level is high) provide all possible risk management strategies for irrigated cotton producers. Therefore, this is consistent with our findings from the above risk analysis.

This risk analysis was conducted at the field level and followed an assumption that lint and seed yields are independent of price changes. This ignored the effect of lint price increase or decrease on encouraging or discouraging investment in input uses for a greater or lesser yield, which may be true at the farm and regional levels. Additionally, sensitivity analysis can be conducted to examine changes in input costs for fertilizers, herbicide, labor, fuel, and irrigation (Pendell, Williams, Boyles, Rice, & Nelson, 2007; Williams et al., 2012). In this study, the net return may be decreased by .1–1% for a 20% increase in input costs. For instance, a 20% increase in labor payment increases production costs by \$1, while a 20% increase in irrigation cost increases the production costs by \$10. Therefore, their influences on CE and RP with respect to varying risk attitudes of producers would not exceed the impacts of price changes presented above.

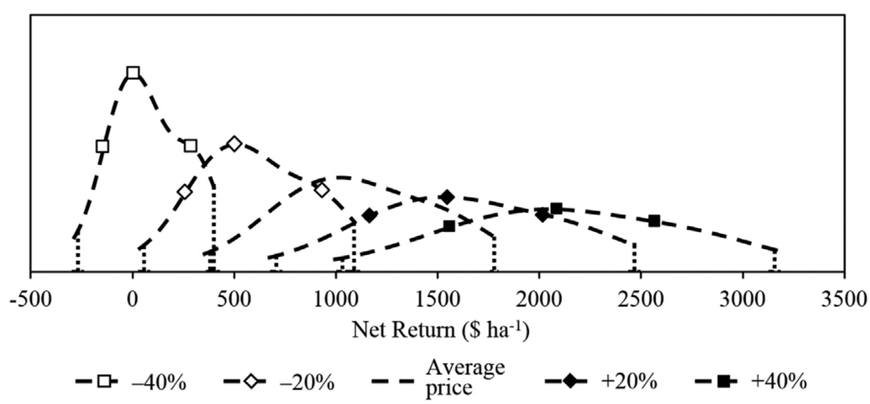

FIGURE 5 Probability density functions of net returns (\$ ha^{-1}) using wheat cover crop at various price levels. Vertical lines show the 5th and 95th percentiles of each distribution

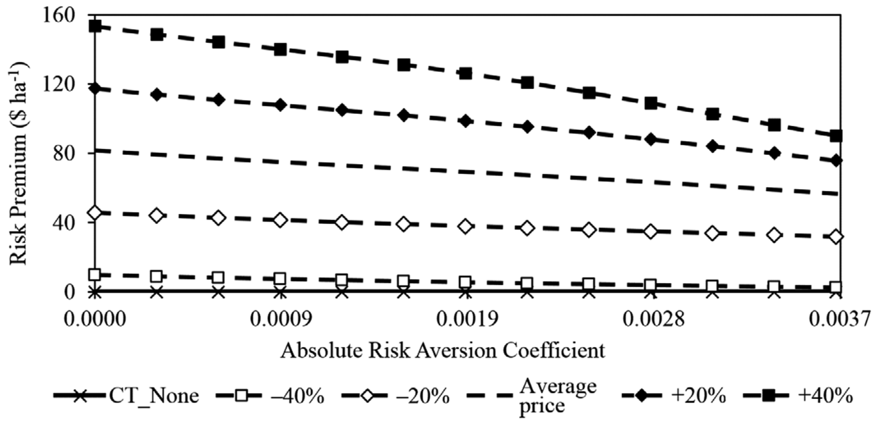

FIGURE 6 Risk premiums ($ ha^{-1}) of using no-till wheat cover crop relative to conventional tillage without cover crops at various price levels

5 | CONCLUSIONS

This study examined the net returns of irrigated cotton production under alternative tillage and cover crop treatments. These treatments included CT and NT without a cover crop, as well as NT with winter wheat and legume–grass mixture cover crops. Field experimental data from 2013 to 2018 were used to calculate net returns of each treatment using partial budget analysis. Risk analysis was conducted using SERF. Sensitivity analysis was conducted on lint and seed prices to examine how the relative net returns and risk preference would change in each treatment.

No-till with wheat cover had the highest average net return, with cover mixture having the second-highest net return calculated using the historical prices. Though the differences were not significant ($P = .8551$), the numeric increases in net returns of both wheat and mixture treatments were mainly due to higher yields, that is, about 7.6% higher in lint yield, than CT and NT without a cover crop. The net returns of NT with wheat and mixed cover crops had a higher variability than the other two treatments without a cover crop, and they also had a much smaller chance of getting a low net return, that is, less than $760 ha^{-1}. Therefore, cover crops can be more beneficial to growers planting NT cotton with appropriate irrigation conditions in semi-arid environments.

Net return variation and grower preferences for conservation practices under alternative levels of risk aversion also provide unique insights. No-till with wheat cover had a higher net return than other treatments and would be preferred by risk-neutral, somewhat risk-averse, and rather risk-averse producers. No-till with mixed cover crops would be preferred by cotton producers with greater levels of risk aversion. Conventional tillage and NT without a cover crop were the least preferred practices, and NT slightly outweighed the CT over the entire range of risk-aversion levels due to cost reduction in tillage operation. The sensitivity analysis showed that the changes in cotton price had a great influence on the variability of net returns and their relative magnitudes in the four scenarios. Nevertheless, NT with wheat and cover mixture would dominate other scenarios across the entire range of risk-aversion levels except for the very low price level close to the breakeven price.

This study quantified and evaluated the net returns associated with the adoption of conservation practices from a risk perspective. Farm-level adoption decisions are influenced by economic considerations relating to input uses and investment decisions as well as government programs and policies (Bergtold, Ramsey, Maddy, & Williams, 2017; Lee & McCann, 2019). This research focused on continuous irrigated cotton systems in semi-arid environments, while evaluation of crop rotation and interaction effects of more practices will provide more insights for the sustainability of cropping systems. Joint evaluation of both dryland and irrigated systems can provide a holistic understanding of conservation practice adoption. Additionally, the pathways to incremental and transformative adoption patterns may be delineated using data from a long-term experiment or simulation model (Carlisle, 2016). Future research can address these issues.

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SUPPORTING INFORMATION

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