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Perceptions of Production Practices and Technologies and the Influence of Information on Willingness to Purchase Food, Plants, and Turfgrasses

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This study examines how various production practices/technology information impacts willingness to purchase food, plants, and turfgrasses. Using an online survey of around 2,100 respondents in the Southeastern United States, we find that providing scientific information about pesticides, GMO, and CRISPR technology reduces consumer willingness to purchase organic food. Providing all information raises willingness to purchase GMO and CRISPR produced foods. Plant results are similar to the food results, except that providing all information increases only the willingness to purchase food produced with CRISPR technologies. Turfgrass results indicate all information positively impacts CRISPR and there is no impact on the information treatments on organic.

***Key words**:* CRISPR; Genetically Modified Organism, Organic, Pesticide

Since 1960, the world population has more than doubled and currently stands at over seven billion people. While the growth rate has slowed, the population is projected to increase to 9.2 billion by 2050. Increasing population, coupled with changing diets in developing countries, will increase demand for food production by 70% (Popp, Pető, and Nagy, 2013). However, crop yield losses to weeds, animal pests, and pathogens remain significant challenges to agricultural production (Oerke and Dehne, 2004). Weeds represent the largest potential threat to crop production (34% crop losses), followed by insects and other animal pests (18%), and fungi and other pathogens (16%) (Oerke, 2006).

To combat production challenges, farmers have increasingly turned to chemical pesticides (herbicides, insecticides, and fungicides) and genetically engineered seeds for crop protection. Since the 1990s pesticide usage has decreased as genetically engineered seeds have become more prevalent in the marketplace (Boyce, 2022). However, pesticides are still applied to a large percentage of acreage within the United States. Notably, herbicides were applied to 97% of the U.S. planted corn acres, 95% of United States soybean acres, and 91% of U.S. cotton acres in 2017. Insecticides were applied to 12% of U.S. corn acres, 19% of U.S. soybean acres, and 43% of U.S. cotton acres. Fungicides were applied to 12% of U.S. corn acres, 14% of U.S. soybean acres, and 1%

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of U.S. cotton acres (United States Department of Agriculture (USDA)–National Agricultural Statistical Service (NASS), 2017; USDA–NASS, 2018a; USDA–NASS, 2018b). Alternatively, fungicides are more prevalent in the production of fruit and vegetables than row crops (Fernandez-Cornejo et al., 2014).

Increased chemical pesticide usage has pushed for the development of crops that can be integrated into production practices, namely genetically modified organisms (GMO) that can tolerate the application of certain herbicides/fungicides/insecticides. The term GMO is typically defined as an organism with DNA from another species inserted into its genome (Huang et al., 2016). Numerous animal and plant species have been genetically modified to gain a myriad of traits, though the most common are crop species with herbicide (e.g., RoundUp Ready and LibertyLink crops) and insect tolerance (e.g., Bt corn) (United States Department of Agriculture – Animal and Plant Health Inspection Service, 2018). Today, over 90% of the United States corn, soybean, and cotton acreage are genetically-modified (United States Department of Agriculture – Economic Research Service, 2019). However, GMOs are not limited to field crops, as eggplant, papaya, pineapple, potatoes, squash, sugarbeets, and apples represent just a few of the bioengineered seeds available for production (USDA–Agricultural Marketing Service, nd).

The combined usage of GMOs and chemical pesticides has largely been beneficial for food production and farmers. Yields are 9% higher for herbicide tolerant crops over non-GMO varieties and 25% higher for insect tolerant crops. Increased yields have translated into increased profits of producers of 68% (Klümper and Qaim, 2014). In addition, though chemical pesticide usage has increased, GMO crops have mitigated this trend, as well as reduced greenhouse gas emissions by changing tillage practices and reducing fuel inputs (Brookes and Barfoot, 2015).

While GMOs have proven useful, they can be expensive and time-consuming to produce (McDougall, 2011). Future gene-editing technologies are expected to help design crops that can help meet food production demand more cheaply and at a faster rate (Huang et al., 2016). At the forefront of new technologies is CRISPR-Cas9, which was first developed and introduced by Drs. Jennifer Doudna and Emmanuelle Charpentier in 2012 (Kim, 2016). Unlike genetic modification technologies, gene editing allows for the direct editing (e.g., DNA cleavage, single nucleotide substitutions) of an organism's genome (i.e., no insertion of DNA from another species), skipping many of the steps involved in genetic modification and allowing for a greater variety of applications.

Chemical pesticides and genetic technologies have allowed much progress in food production, but public perception of them has remained mixed. Almost seven out of every ten United States adults consider eating foods grown with pesticides to be generally unsafe (Pew Research Center, 2015a). Favorable views are slightly higher among men (38% favorable) and Caucasians (33%) (Pew Research Center, 2015a), while households with children, suburban households, and households with lower incomes tend to be more averse to pesticides (Govindasamy et al., 1998).

Perceptions of genetically modified foods are similar: almost six out of ten United States adults see them as unsafe (Pew Research Center, 2015a). These largely negative views, though, stand in stark contrast with scientists affiliated with the American Association for the Advancement of Science: almost seven out of ten see genetically modified foods as safe (Pew Research Center, 2015b). Nevertheless, the mixed to negative views of pesticides and GMOs have driven the demand for organic food production that limits/prohibits these technologies (reviewed in Lotter, 2003). In addition, labeling of GMO foods, which was signed into law by President Obama in 2016, has broad support (Berning and Campbell, 2017).

As pesticide, GMO, and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) use increases, it is essential to understand how providing scientific information will impact consumer willingness to purchase products that use these production practices and technologies. Therefore, the objective of this paper was to understand how providing scientific information on a production practice (i.e., CRISPR, GMO, pesticides, organic) impacts not only the perception of that practice, but the perception of other production practices. Specifically, we investigate the following questions: 1) How knowledgeable do people feel about various chemical pesticides, genetic modification, organic, and gene editing (i.e., CRISPR)? 2) How are production practices perceived as noted by a respondent's willingness to buy products made with specific production technologies? 3) Does providing information about a production practice influence how the practice is perceived? 4) How does information about a production practice impact a respondent's views about other production practices? 5) Does acceptance of a type of production practice vary by type of product (food, plants, turfgrass)?

Data and Methodology

In the spring of 2018, an online survey was administered in the states of Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee within the United States. Potential respondents were asked to participate via e-mail from the database of Toluna, Inc. with respondents choosing to participate being directed to the study. The survey was restricted to respondents 18 years old or older. Around 2,500 respondents completed the survey.

Table 1. Descriptive statistics of respondents for a 2019 perceptions survey of Southeast states residents on production practices and technologies.

Attribute	Sample - Mean	Sample - Standard Deviation
Age (median years)	41	
Household income	$54,465	$45,146
Caucasian	71.20%	
Female	64.00%	
Adults in household	2.1	1.1
Children in household	0.8	1.2
Generation		
Older	34.50%	
Generation X	39.40%	
Youth	26.10%	
Education		
High school or less	32.40%	
Some college	37.00%	
Bachelor's degree	19.60%	
Graduate degree	11.00%	
Political affiliation		
Republican	32.80%	
Democrat	33.10%	
Other	34.00%	
Urbanicity [a]		
Rural	37.30%	
Suburban	47.40%	
Metro	15.20%	

[a] *Percentages may not sum to 100% due to rounding.*

Demographic information of the respondents is largely representative of those states. For instance, the median survey respondent age was 41 compared to the 38 years for the Southeastern United States (U.S. Census Bureau, 2019b) (Table 1). The slightly higher median age is due to survey respondents having to be 18 years of age or older, which biased the survey age upward. Seventy-one percent of respondents identified as Caucasian which is similar to the 70% for the Southeast reported by the census (U.S.

Census Bureau, 2019a). Other variables, such as urban/rural of household and respondents' political affiliation were included. Urban/rural and political affiliation have been shown to play a role in consumer decision making (Campbell, Campbell, and Berning, 2021; San Fratello et al., 2022). Though we cannot guarantee the generalizability of the sample, it includes a range of demographics, political affiliations, etc. The representativeness of the sample provides support that the survey's findings can be extrapolated to a wider population.

Table 2. Information treatment groups used in a 2019 perceptions survey on production practices and technologies to test impacts of information on the impact of purchasing of food, landscaping, or turfgrass products.

	Statement
Control – No information	-------
Pesticides	**Insecticide**: a pesticide that is used to eliminate or repel insects. **Fungicide**: a pesticide that is used to eliminate or prevent the growth of fungi, molds, and their spores. **Herbicide**: a pesticide that is used to eliminate or prevent the growth of plants.
Genetically Modified Organism (GMO)	An organism in which the genetic material (DNA) has been altered through the use of modern biotechnololgies. The alteration typically involves transferring DNA from one organism to another.
CRISPR	A new biotechnology that allows scientists to directly edit an organism's genetic material (DNA). This does not require transferring DNA from one organism to another.
CRISPR and GMO	**CRISPR**: a new biotechnology that allows scientists to directly edit an organism's genetic material (DNA). This does not require transferring DNA from one organism to another. **Genetically Modified Organism (GMO)**: an organism in which the genetic material (DNA) has been altered through the use of modern biotechnologies. The alteration typically involves transferring DNA from one organism to another.
Organic	The application of a set of cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity. These include maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife; and avoiding use of synthetic fertilizers, sewage sludge, irradiation, and genetic engineering.
All information	**CRISPR**: a new biotechnology that allows scientists to directly edit an organism's genetic material (DNA). This does not require transferring DNA from one organism to another. **Genetically Modified Organism (GMO)**: an organism in which the genetic material (DNA) has been altered through the use of modern biotechnologies. The alteration typically involves transferring DNA from one organism to another. **Insecticide**: a pesticide that is used to eliminate or repel insects. **Fungicide**: a pesticide that is used to eliminate or prevent the growth of fungi, molds, and their spores. **Herbicide**: a pesticide that is used to eliminate or prevent the growth of plants. **Organic**: the application of a set of cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity. These include maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife; and avoiding use of synthetic fertilizers, sewage sludge, irradiation, and genetic engineering.

Experimental Design and Analysis

To begin the survey, respondents were asked how knowledgeable they felt about the following production practices and technologies: insecticides, herbicides, fungicides, genetically modified organisms (GMOs), CRISPR technology, and organic practices. Respondents answered the question via marking their perceived knowledge on a continuous line scale where 0 = no knowledge, 50 = somewhat knowledgeable, and 100 = extremely knowledgeable.

Respondents were randomly assigned to one of six treatment groups and presented with the statements shown in Table 2. There were about 360 respondents in each treatment group. Respondents were then asked how the use of production practices/technologies (listed in Table 2) would impact their decision to purchase food products, plants for landscaping, and turfgrasses for a residence's grassy areas. Food, plants, and turfgrass were chosen given they serve different roles in a home. For instance, food is ingested into the body, while plants may or may not be ingested (depends on type of plant) and may serve different roles around the home. Turfgrass, on the other hand, is not ingested into the body but serves as a location for outdoor activities. Respondents answered questions via marking their willingness to purchase on a continuous line scale where 0 = extremely less likely to purchase, 50 = no impact on decision to purchase, and 100 = extremely more likely to purchase. The order of product (i.e., food, plant, turfgrass) was randomized as was the order of production practice (i.e., chemical pesticide, organic, GMO, CRISPR) in order to help mitigate order bias.

Because responses are bounded between 0 and 100 on their willingness to purchase, more extreme responses (i.e., < 0 and > 100) are censored. Failure to account for the censored nature of the data can bias results. A two-limit Tobit model was proposed as a model to help minimize the bias associated with censored data (Rossett and Nelson, 1975). The model can be represented as:

(1)
$$y^*_i = \beta' x_i + \varepsilon_i \quad (i = 1, \ldots, n)$$
$$y_i = \begin{cases} 0 & if\ y_i^* \leq 0 \\ y_i^* & if\ 0 < y_i^* < 100 \\ 100 & if\ y_i^* \geq 100 \end{cases} \quad (i = 1, \ldots, n)$$

where yi* is a latent variable that is not observed at values below 0 or values above 100, x is a matrix of explanatory variables, β is a vector of coefficients, and ε is an independently and normally distributed error term with zero mean and variance σ2. The x matrix of explanatory variables included demographics, state residence, political affiliation, urbanicity, shopping responsibility, perceived knowledge of the practices, and treatment indicators. Political affiliation and urbanicity were included in order to control for respondent views on the production practices and technologies so that the treatment group impacts could be isolated. Coefficient estimates were maximized using the likelihood function in equation two (Davidson and McKinnon, 1993):

$$(2) \quad \sum_{y_t^L \leq y_t^* \leq y_t^U} log\left(\frac{1}{\sigma}\emptyset\left(\frac{1}{\sigma}(y_t - x_t\beta)\right)\right) + \sum_{y_t^* < y_t^L} log\left(\phi\left(\frac{1}{\sigma}(y_t^L - x_t\beta)\right)\right) + \sum_{y_t^* > y_t^U} log\left(\phi\left(-\frac{1}{\sigma}(y_t^U - x_t\beta)\right)\right)$$

The estimated β coefficients from equation (2) are not interpretable as marginal effects (Gould et al., 1989). Tobit results can be decomposed into unconditional marginal effects, conditional marginal effects, and the probabilities of being uncensored by using the McDonald and Moffitt decomposition (McDonald and Moffitt, 1980). We report the conditional marginal effects.

Only the conditional marginal effects are reported in this paper. The conditional marginal effects represent changes from the mean (i.e., for continuous variables) or changes from the base values (i.e., for categorical variables) for those responses within the bounds. Analyses were conducted using Stata/SE 14.2 (StataCorp LLC, College Station, Texas).

Results and Discussion

Of the ~2100 respondents, people indicated they felt less than somewhat knowledgeable about all the production practices and technologies, though they felt the least knowledgeable about CRISPR (Table 3). The range was between 31.9 (i.e., for CRISPR) and 47.4 (i.e., for insecticides). When given no information about the technologies, people were most comfortable purchasing foods (Table 4), landscaping plants (Table 5), and turfgrasses (Table 6) that had been cultivated through organic means, though this effect was more pronounced for foods than the other categories (64.0, 61.6, and 59.7, respectively). Overall, people were less willing to buy foods cultivated with pesticides and genetic technologies than they were landscaping and turfgrasses cultivated with the same production practices.

When given information on all the technologies, people were more likely to be inclined to buy foods that are GMOs (45.9 vs 43.5) or produced through CRISPR (46.0 vs 43.8) (Table 4). The inclination to purchase GMO and CRISPR foods was also seen for landscaping produced through CRISPR (47.7 vs 43.9) (Table 5). Similarly, people were less likely to purchase organic foods if they were provided with information on

GMOs (59.9 vs 64.0), GMOs and CRISPR (60.5 vs 64.0), or pesticides (62.0 vs 64.0) (Table 4). This pattern was also seen for landscaping plants if they were provided with information on GMOs (56.2 vs 61.6) or pesticides (59.4 vs 61.6) (Table 5). Concerning turfgrasses, people were more likely to buy grasses grown through CRISPR if they were provided information on all the technologies (49.2 vs 45.5) (Table 6).

Table 3. Means and standard deviations of perceived knowledge about production practices and technologies from a 2019 perceptions survey.

	Perceived knowledge (0 to 100 scale) [a]	
Practice or technology	Mean	Standard Deviation
Insecticides	47.4	29.2
Herbicides	45.1	29.5
Fungicides	41.3	30
GMOs	43.7	30.5
CRISPR	31.9	30.7
Organic	47.3	30.2

a 0 = no knowledge, 50 = somewhat knowledgeable, 100 = extremely knowledgeable.

Table 4. Means and standard deviations of the impact production practices and technologies have on buying foods from a 2019 perceptions survey. The treatment types correspond to what information respondents received during the survey.

	Likelihood of purchasing (0 to 100 scale) [a]													
Practice or technology	Control		All		Pesticides		GMO		CRISPR		GMO & CRISPR		Organic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Insecticides	42	31.8	44.3	29.1	45.6	29.7	40.5	32	42.2	29.5	41.3	30.5	41.1	29.7
Herbicides	45.2	31.2	44.5	28.9	46.8	28.5	42.5	31.5	43.7	28	44.5	29.7	43.1	29
Fungicides	42.7	31.1	44.4	29	46.7	28.7	41.1	30.6	42.6	29.3	41.9	29.6	41.4	29.1
GMOs	43.5	32.2	45.9	30.1	45	29.8	41.2	31	42	29.5	42.9	29.8	43.2	30.1
CRISPR	43.8	29.8	46	28.3	45.3	28.5	40.1	29.4	45.6	27.4	44.7	29.2	42.2	29.7
Organic	64	30.2	62.2	29.7	62	28.3	59.9	31.9	60.8	28.7	60.5	28.9	61.5	29.9

[a] 0 = extremely less likely to purchase , 50 = no impact on decision to purchase , 100 = extremely more likely to purchase. Note: SD = standard deviation.

Table 5. Means and standard deviations of the impact production practices and technologies have on buying landscaping plants from a 2019 perceptions survey. The treatment types correspond to what information respondents received during the survey.

	Likelihood of purchasing (0 to 100 scale) [a]													
Practice or technology	Control		All		Pesticides		GMO		CRISPR		GMO & CRISPR		Organic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Insecticides	46.5	31	46.1	28.1	48.4	28.3	44.4	30.3	46.5	27.8	44.2	28.5	45.5	28.1
Herbicides	47.3	30.4	45.4	28.4	49.7	28	45.7	29.9	48.5	27.2	46.1	28	45.8	27.1
Fungicides	44.9	29.6	45.1	27.7	47.6	28.2	44.1	29.9	45.6	26.5	45.4	28.4	44.6	27.7
GMOs	44.3	31.3	45.5	27.9	46.3	29.4	41.2	29.8	44	28	44.9	28.5	43.3	28.9
CRISPR	43.9	29.2	47.7	27.1	45.7	27.6	41.4	29.2	46.6	26.4	46.6	28.3	42.6	29.2
Organic	61.6	29.7	61.3	28.2	59.4	27.7	56.2	30.9	59.1	28.1	59.1	29.2	60.3	29

[a] *0 = extremely less likely to purchase , 50 = no impact on decision to purchase , 100 = extremely more likely to purchase. Note: SD = standard deviation.*

Table 6. Means and standard deviations of the impact production practices and technologies have on buying turfgrasses from a 2019 perceptions survey. The treatment types correspond to what information respondents received during the survey.

	Likelihood of purchasing (0 to 100 scale) [a]													
Practice or technology	Control		All		Pesticides		GMO		CRISPR		GMO & CRISPR		Organic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Insecticides	47.8	29.6	48.2	29.2	48.1	27.4	44.7	30.1	45.3	27.2	45.5	28.8	44.2	27.9
Herbicides	47.8	29	47.8	28.3	48.7	27.9	43.8	29.9	48.1	26.8	46.5	28.3	45	27.7
Fungicides	47.6	28.9	47	28.6	48.5	27.8	42.9	29.6	46	26.7	45.7	28	44.1	27.3
GMOs	44.6	29.2	47	29.4	46.3	28.6	42.2	29.7	44.5	28.4	46.6	29.2	43.1	28
CRISPR	45.5	27.4	49.2	28.2	46.2	26.9	41.6	28.5	47	26.4	47.1	28.1	43.4	28.2
Organic	59.7	29	59.3	29.5	57.3	27.9	56	30.6	58.7	28	57.2	29.2	58.2	29

[a] *0 = extremely less likely to purchase , 50 = no impact on decision to purchase , 100 = extremely more likely to purchase. Note: SD = standard deviation.*

Tobit Model Results: Marginal Effects Conditional on being Uncensored

In comparing demographics, select characteristics were seen to impact the likelihood of buying foods, landscaping plants, and turfgrasses grown with different production practices and technologies (Tables 7, 8, and 9). While significant coefficients and associated magnitudes depend on the product and practice, Generation X and younger individuals tend to be more likely to buy products grown with pesticides or genetic technologies and less likely to buy organic. For instance, Gen X and Millennial respondents were 2.4% and 3.0% more likely to say they would purchase a turfgrass produced using insecticides, respectively (Table 9). Gen X and Millennials were 2.3% and 3.5% more likely to purchase a GMO food, respectively (Table 7). The same patterns can be seen in males, especially for plants (Table 8) and turfgrasses (Table 9).

Political affiliation had no effect on food products (Table 7), but Republicans were more likely to buy plants grown with herbicides (+1.9%) and CRISPR (+2.6%) (Table 8), and buy turfgrasses grown with insecticides, herbicides, fungicides, and genetic modifications (range: +1.8% to +2.3%) (Table 9). Interestingly, having more children increased the likelihood of buying foods grown with insecticides (+0.6% for each child), fungicides (+0.8%), and genetic modifications (+0.8%) (Table 7), as well as plants grown with insecticides (+0.7%) and genetic modifications (+0.8%) (Table 8). Rural respondents were less likely to buy food (-2.6%) (Table 8) and turfgrass grown with herbicides (-2.1%) (Table 9). People with higher incomes were more likely to buy food products grown with insecticides and herbicides (Table 7) and landscape products grown with insecticides, herbicides, and fungicides, but the coefficients for these effects were not much greater than zero.

With respect to perceived knowledge of the technologies and practices, there is a positive impact on the purchase of any of the products (range: +0.2% for insecticides on turfgrasses to +0.4% for organic foods) (Tables 7-9). This implies that when a respondent perceived they had better knowledge of the production practice, they were more likely to indicate they would purchase a food, plant, and/or turfgrass that had been produced with that practice.

Examining the information treatment effect for foods, none of the information treatments impacted respondent willingness to purchase a product that was produced using insecticides, herbicides, or fungicides (Table 7). This is also the case for GMO, CRISPR, and GMO/CRISPR in that providing information about these technologies does not impact a respondent's willingness to purchase food that was produced using the technology (Table 7). However, providing information about pesticides, GMO, or GMO/CRISPR had a negative impact on a respondent's willingness to purchase organic food (Table 7). In essence, if respondents were informed about production practices and technologies that are generally found as unfavorable, it had a negative impact on a respondent's view of organic production practices. Furthermore, providing all the information resulted in a positive increase in the willingness to purchase both GMO and CRISPR foods (Table 7). Most likely this is due to respondents being provided information about all the production practices/technologies so that they can be more fully informed consumers.

The plant results are similar to the food results in that pesticide and GMO information had a negative impact on the willingness to purchase organic plants. Similarly, respondents receiving all information were more likely to purchase CRISPR produced plants with no difference between the control for GMO plants (Table 8). In comparison, for turfgrass the only significant treatment is for all information on CRISPR (Table 9). Providing full information (i.e., organic, CRISPR, pesticide, and GMO) had a positive effect on purchasing a plant produced using CRISPR (Table 8). However, for turfgrass compared to food and plants, none of the treatments impacted organic (Table 9).

Table 7. Tobit results estimating conditional marginal effects on buying *foods* from a 2019 perceptions survey on production practices and technologies.

	Insecticides		Herbicides		Fungicides		GMO		CRISPR		Organic	
	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE
State												
AL	-0.93	1.76	0.30	1.78	-2.28	1.75	-1.53	1.77	-1.34	1.74	0.63	1.68
GA	-2.12	1.49	-0.65	1.50	-2.32	1.49	-3.36 **	1.49	-3.56 **	1.46	0.35	1.42
KY	-0.87	1.77	-1.74	1.78	-2.27	1.77	-1.27	1.76	-3.13 *	1.72	-0.89	1.68
LA	-3.09 *	1.77	-1.28	1.79	-3.43 *	1.78	-1.62	1.78	-3.39 *	1.76	-0.31	1.68
MS	-1.64	1.84	-1.72	1.87	-3.55 *	1.85	-1.72	1.86	-3.60 **	1.81	-1.53	1.75
NC	-1.38	1.71	-1.91	1.73	-2.23	1.72	-2.31	1.71	-2.28	1.68	0.72	1.63
SC	-2.32	1.69	-1.76	1.72	-3.47 **	1.70	-2.97 *	1.71	-5.12 ***	1.67	-2.30	1.62
TN	-3.04 *	1.68	-2.90 *	1.70	-4.20 **	1.67	-2.43	1.69	-4.74 ***	1.64	-1.09	1.60
Generation												
Gen X	2.61 ***	0.95	2.26 **	0.97	1.97 **	0.95	2.32 **	0.96	-0.39	0.96	-1.34	0.91
Young	3.45 ***	1.10	2.62 **	1.11	1.56	1.09	3.49 ***	1.10	-1.18	1.09	-3.10 ***	1.04
Caucasian	-3.07 ***	1.00	-2.96 ***	1.01	-3.08 ***	0.99	-2.14 **	1.00	-1.01	0.98	1.94 **	0.95
Male	2.54 ***	0.83	2.21 ***	0.84	2.51 ***	0.83	2.84 ***	0.83	2.33 ***	0.82	-2.80 ***	0.79
Shopping Responsibility												
Not Primary Shopper	0.60	1.74	0.58	1.78	-0.07	1.75	-0.80	1.76	-2.37	1.71	-2.84 *	1.67
Primary Shopper Shared	-2.75 ***	1.06	-2.62 **	1.07	-2.41 **	1.06	-3.81 ***	1.07	-1.69	1.06	-0.78	1.00
Politics												
Republican	-0.49	1.02	0.25	1.03	0.67	1.02	-0.50	1.02	0.57	1.00	0.67	0.97
Politics – Other	-2.41 **	0.98	-1.79 *	0.99	-1.68 *	0.97	-2.95 ***	0.98	-1.39	0.95	-0.38	0.92
Education												
High School or Less	3.55 ***	1.17	2.58 **	1.19	3.22 ***	1.17	3.30 ***	1.18	-0.58	1.16	-1.22	1.11
Some College	0.65	1.11	-0.21	1.12	0.86	1.11	1.33	1.11	-0.51	1.10	0.38	1.05
Grad School or Higher	2.65 *	1.45	1.20	1.47	2.30	1.44	3.50 **	1.45	1.11	1.42	-0.81	1.38
Household												
# Children	0.62 *	0.36	0.32	0.37	0.76 **	0.36	0.77 **	0.37	0.43	0.36	0.08	0.34
# Adults	-0.10	0.39	-0.09	0.40	-0.17	0.40	0.17	0.39	0.38	0.39	0.59	0.38
Urbanicity												
Suburban	-0.23	1.17	-1.47	1.18	-0.24	1.16	-0.74	1.16	1.30	1.14	0.70	1.12
Rural	-1.09	1.24	-2.57 **	1.25	-1.35	1.23	-1.45	1.24	-0.67	1.22	0.24	1.18
Household Income in 2018 [a]	0.02 *	0.01	0.02 *	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
Treatments												
CRISPR	0.26	1.45	-0.94	1.46	-0.62	1.44	-0.54	1.45	1.54	1.41	-1.87	1.37
Organic	0.56	1.47	-0.44	1.47	-0.99	1.46	0.34	1.46	-0.29	1.43	-0.83	1.39
GMO	-0.86	1.46	-1.82	1.47	-1.90	1.45	-0.90	1.46	-2.29	1.43	-2.68 *	1.38
GMO & CRISPR	-0.26	1.44	-0.97	1.45	-2.16	1.44	-0.37	1.44	-0.14	1.41	-2.70 **	1.36
All	1.29	1.46	-0.60	1.46	1.08	1.45	2.96 **	1.46	2.35 *	1.42	-1.06	1.38
Pesticides	2.10	1.43	0.41	1.44	0.64	1.43	0.58	1.44	0.10	1.40	-2.33 *	1.37
Knowledge	0.27 ***	0.01	0.28 ***	0.01	0.30 ***	0.01	0.27 ***	0.01	0.39 ***	0.01	0.35 ***	0.01
/sigma	28.939		27.939		27.447		28.658		24.909		28.519	
/sigma SE	0.476		0.459		0.455		0.474		0.416		0.484	
/sigma CI lower	28.006		27.039		26.555		27.729		24.093		27.569	
/sigma CI upper	29.873		28.839		28.339		29.588		25.725		29.469	
Observations	2,132		2,121		2,106		2,111		2,038		2,196	
LR chi2	517.48		539.47		636.800		577.040		886.920		734.490	
Prob > chi2	0.000		0.000		0.000		0.000		0.000		0.000	
Log likelihood	-9492.53		-9422.5982		-9274.396		-9367.681		-8839.380		-9200.739	
Pseudo R2	0.027		0.0278		0.033		0.030		0.048		0.038	
Lower Bound	4.55%		3.91%		4.42%		4.74%		4.32%		1.73%	
Upper Bound	4.64%		4.71%		4.84%		4.59%		4.17%		13.75%	

[a] *Household income represents a change in $1,000. Significance values: * p < 0.1, ** p < 0.05, *** p < 0.01.*

Table 8. Tobit results estimating conditional marginal effects on buying landscaping plants from a 2019 perceptions survey on production practices and technologies.

	Insecticides			Herbicides			Fungicides			GMO			CRISPR			Organic		
	Marg. Eff.		SE	Marg. Eff.		SE	Marg. Eff.		SE	Marg. Eff.		SE	Marg. Eff.		SE	Marg. Eff.		SE
State																		
AL	-2.22		1.78	-0.14		1.79	-1.21		1.78	-1.19		1.80	-2.62		1.74	-0.82		1.71
GA	-2.79	*	1.51	-0.82		1.50	-1.96		1.50	-1.85		1.51	-3.46	**	1.47	0.46		1.44
KY	-1.39		1.79	-0.99		1.79	-2.02		1.78	-0.65		1.80	-4.11	**	1.74	-0.04		1.70
LA	-3.01	*	1.80	-0.32		1.80	-1.72		1.78	-1.17		1.80	-3.34	*	1.78	0.79		1.70
MS	-3.43	*	1.88	-2.21		1.87	-3.23	*	1.87	-2.18		1.89	-4.43	**	1.83	-1.62		1.78
NC	-1.95		1.73	-2.18		1.73	-1.72		1.73	0.19		1.74	-2.45		1.69	0.48		1.65
SC	-2.90	*	1.73	-2.19		1.72	-2.68		1.72	-2.17		1.74	-5.26	***	1.68	-2.73	*	1.65
TN	-4.19	**	1.71	-1.94		1.70	-0.85		1.69	-2.98	*	1.71	-5.18	***	1.65	-0.62		1.62
Generation																		
Gen X	2.13	**	0.97	1.59	*	0.96	0.97		0.96	1.28		0.98	-0.60		0.96	-1.93	**	0.92
Young	4.07	***	1.10	2.85	***	1.10	2.37	**	1.10	2.25	**	1.12	-1.57		1.10	-2.59	**	1.05
Caucasian	-3.05	***	1.01	-2.68	***	1.00	-2.27	**	1.00	-2.00	**	1.02	-1.65	*	0.98	1.34		0.96
Male	1.41	*	0.85	0.73		0.84	0.65		0.84	2.72	***	0.84	1.02		0.82	-0.67		0.80
Shopping Responsibility																		
Not Primary Shopper	1.20		1.77	1.07		1.78	1.22		1.77	-0.76		1.78	-0.54		1.71	-4.11	**	1.70
Primary Shopper Shared	-2.65	**	1.08	-2.34	**	1.07	-2.44	**	1.07	-3.90	***	1.09	-2.50	**	1.06	-0.92		1.01
Politics																		
Republican	1.09		1.04	1.85	*	1.03	0.50		1.03	0.91		1.04	2.54	**	1.01	0.64		0.99
Politics – Other	-1.35		0.99	-0.95		0.98	-1.72	*	0.98	-1.58		0.99	-0.82		0.96	-0.30		0.94
Education																		
High School or Less	1.24		1.19	0.73		1.18	2.49	**	1.18	1.91		1.20	-1.59		1.16	-2.35	**	1.13
Some College	1.20		1.12	-0.51		1.12	1.52		1.12	0.27		1.13	0.22		1.10	1.29		1.07
Grad School or Higher	1.26		1.46	-0.14		1.47	1.09		1.46	2.24		1.48	0.37		1.44	-1.12		1.40
Household																		
# Children	0.69	*	0.37	0.05		0.37	0.35		0.37	0.83	**	0.37	0.48		0.36	0.22		0.35
# Adults	-0.18		0.40	-0.36		0.40	-0.05		0.40	-0.69	*	0.40	0.34		0.39	0.57		0.38
Urbanicity																		
Suburban	1.47		1.19	-0.87		1.18	0.32		1.17	-1.19		1.18	0.69		1.14	0.64		1.13
Rural	1.08		1.26	-1.04		1.25	-0.10		1.24	-1.12		1.26	0.41		1.22	0.59		1.20
Household Income in 2018 [a]	0.02	*	0.01	0.02	**	0.01	0.02	**	0.01	0.01		0.01	0.00		0.01	-0.000		0.01
Treatments																		
CRISPR	0.45		1.47	0.82		1.46	-0.22		1.45	-0.25		1.47	1.94		1.42	-0.78		1.39
Organic	0.30		1.48	-1.18		1.48	-1.54		1.47	-0.70		1.49	-0.61		1.44	0.13		1.40
GMO	-0.92		1.48	-1.09		1.47	-0.84		1.46	-1.63		1.48	-1.50		1.44	-2.64	*	1.39
GMO & CRISPR	-0.51		1.46	-0.54		1.46	0.02		1.46	0.65		1.46	1.64		1.42	-0.95		1.38
All	-0.55		1.48	-2.25		1.46	-0.44		1.46	0.89		1.49	3.13	**	1.43	0.98		1.39
Pesticides	1.29		1.47	0.75		1.45	0.34		1.45	0.78		1.46	0.02		1.41	-2.74	**	1.38
Knowledge	0.30	***	0.01	0.32	***	0.01	0.33	***	0.01	0.26	***	0.01	0.39	***	0.01	0.36	***	0.01
/sigma	27.163			26.383			25.745			27.828			24.349			27.308		
/sigma SE	0.442			0.429			0.421			0.461			0.405			0.459		
/sigma CI lower	26.296			25.542			24.919			26.925			23.554			26.408		
/sigma CI upper	28.031			27.224			26.571			28.731			25.143			28.207		
Observations	2,136			2,132			2,103			2,103			2,029			2,175		
LR chi2	543.810			607.750			662.110			511.590			874.590			767.670		
Prob > chi2	0.000			0.000			0.000			0.000			0.000			0.000		
Log likelihood	-9487.136			-9433.754			-9261.720			-9308.109			-8819.738			-9212.353		
Pseudo R2	0.028			0.031			0.035			0.027			0.047			0.040		
Lower Bound	3.46%			3.14%			3.14%			4.37%			3.35%			1.66%		
Upper Bound	4.49%			4.50%			4.47%			4.61%			4.29%			11.72%		

[a] *Household income represents a change in $1,000. Significance values: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.*

Table 9. Tobit results estimating conditional marginal effects on buying *turfgrass* from a 2019 perceptions survey on production practices and technologies.

	Insecticides		Herbicides		Fungicides		GMO		CRISPR		Organic	
	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE	Marg. Eff.	SE
State												
AL	-1.94	1.83	-2.57	1.82	-1.20	1.81	-3.45 *	1.81	-1.92	1.80	-1.84	1.71
GA	-1.84	1.53	-2.06	1.53	-1.31	1.53	-2.25	1.52	-0.41	1.51	0.71	1.45
KY	-1.68	1.83	-3.15 *	1.82	-0.97	1.82	-2.40	1.80	-1.30	1.80	-1.48	1.72
LA	-2.31	1.83	-2.77	1.82	-1.37	1.81	-4.43 **	1.81	-1.00	1.81	0.52	1.73
MS	-2.19	1.91	-3.31 *	1.91	-3.02	1.90	-4.97 ***	1.91	-2.47	1.89	-1.36	1.79
NC	-2.53	1.76	-3.24 *	1.75	-2.45	1.75	-4.15 **	1.74	-2.74	1.74	-1.20	1.66
SC	-1.38	1.76	-3.50 **	1.76	-2.39	1.75	-3.84 **	1.75	-4.36 **	1.75	-4.18 **	1.66
TN	-2.74	1.74	-3.55 **	1.73	-2.71	1.73	-2.95 *	1.72	-4.37 **	1.71	-1.38	1.63
Generation												
Gen X	2.04 **	0.99	1.46	0.98	0.88	0.98	1.48	0.98	1.27	0.98	-0.50	0.93
Young	2.98 ***	1.13	1.70	1.13	2.24 **	1.13	2.38 **	1.12	2.86 **	1.13	-2.09 **	1.06
Caucasian	-3.16 ***	1.03	-2.09 **	1.03	-2.40 **	1.02	-2.74 ***	1.03	-1.50	1.02	1.78 *	0.97
Male	2.81 ***	0.86	2.39 ***	0.85	2.61 ***	0.85	2.72 ***	0.85	2.78 ***	0.85	0.00	0.81
Shopping Responsibility												
Not Primary Shopper	-1.37	1.80	-2.11	1.80	-2.02	1.79	-0.07	1.80	-1.40	1.80	-2.45	1.70
Primary Shopper Shared	-2.72 **	1.09	-3.46 ***	1.09	-3.66 ***	1.09	-3.95 ***	1.09	-3.63 ***	1.09	-1.04	1.03
Politics												
Republican	2.09 **	1.06	2.33 **	1.05	1.83 *	1.05	1.83 *	1.05	0.70	1.05	0.15	1.00
Politics – Other	-1.37	1.01	-1.44	1.00	-1.89 *	1.00	-0.94	1.00	-1.76 *	1.00	-1.09	0.95
Education												
High School or Less	1.90	1.21	0.00	1.21	1.27	1.20	1.39	1.20	-0.73	1.20	-1.01	1.14
Some College	-0.03	1.15	-1.05	1.15	-0.89	1.14	-0.21	1.14	-2.02 *	1.14	0.53	1.08
Grad School or Higher	2.30	1.50	0.84	1.50	2.90 *	1.49	2.75 *	1.49	2.03	1.50	-1.28	1.42
Household												
# Children	0.21	0.37	0.56	0.37	0.44	0.37	0.15	0.37	0.57	0.37	-0.26	0.35
# Adults	0.59	0.41	0.46	0.41	0.43	0.40	0.77 *	0.41	0.58	0.41	1.03 ***	0.38
Urbanicity												
Suburban	-0.30	1.22	-1.02	1.21	-0.73	1.21	-0.39	1.21	0.51	1.20	-0.91	1.14
Rural	-1.23	1.29	-2.14 *	1.28	-1.76	1.28	-0.95	1.28	-0.49	1.27	-0.65	1.21
Household Income in 2018 [a]	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
Treatments												
CRISPR	-1.41	1.51	0.40	1.50	-1.21	1.49	-0.20	1.49	0.82	1.48	0.35	1.41
Organic	-1.66	1.53	-1.02	1.52	-1.48	1.52	-0.45	1.51	-0.30	1.51	0.12	1.43
GMO	-1.25	1.51	-1.76	1.50	-2.33	1.50	-0.25	1.50	-1.89	1.50	-1.31	1.41
GMO & CRISPR	-1.02	1.50	-0.29	1.49	-0.61	1.48	2.37	1.48	1.86	1.48	-0.22	1.40
All	-0.13	1.51	0.34	1.51	-0.36	1.50	1.27	1.50	2.95 **	1.50	0.75	1.41
Pesticides	-0.23	1.50	0.21	1.49	0.24	1.49	0.96	1.48	0.80	1.48	-1.59	1.40
Knowledge	0.22 ***	0.01	0.26 ***	0.01	0.25 ***	0.01	0.25 ***	0.01	0.28 ***	0.01	0.37 ***	0.01
/sigma	28.400		27.001		27.017		27.702		25.946		26.948	
/sigma SE	0.469		0.441		0.442		0.455		0.426		0.451	
/sigma CI lower	27.481		26.136		26.150		26.809		25.110		26.064	
/sigma CI upper	29.319		27.866		27.884		28.594		26.783		27.832	
Observations	2,121		2,115		2,119		2,100		2,092		2,158	
LR chi2	377.540		475.060		471.680		463.150		548.650		772.350	
Prob > chi2	0.000		0.000		0.000		0.000		0.000		0.000	
Log likelihood	-9437.445		-9408.710		-9408.603		-9366.143		-9227.289		-9219.967	
Pseudo R2	0.020		0.025		0.025		0.024		0.029		0.040	
Lower Bound	3.49%		3.17%		3.30%		4.10%		3.82%		2.13%	
Upper Bound	5.47%		4.49%		4.62%		3.86%		3.87%		10.06%	

[a] *Household income represents a change in $1,000. Significance values: * p < 0.1, ** p < 0.05, *** p < 0.01.*

Conclusions

While respondents felt less than somewhat knowledgeable about pesticides, genetic technologies, and organic methods, they still felt most comfortable purchasing foods, landscaping plants, and turfgrasses that had been organically cultivated. This preference for organic was stronger for foods than for the other products, indicating that people are more precautionary about chemical and genetic technologies involving products that they consume. However, providing information about production practices had an ameliorating effect: people were more likely to buy certain products cultivated with these practices, as well as less likely to buy organic. Certain demographic factors also had sizeable effects in predicting how likely people were to buy specific products.

As previous Pew survey research has shown, foods grown with pesticides and genetic technologies are considered by most to be unsafe (Pew Research Center, 2015a), and our findings largely support this position. Across all treatments, people were about 15 to 20 points on the scale more comfortable buying organic foods than any of the others. This effect was slightly less (i.e., 10 to 15 points on the scale more comfortable) for landscaping plants and turfgrasses, but the pattern is largely identical: people consider products grown using pesticides and/or genetic technologies to be unsafe. This is despite the plethora of benefits provided by the use of pesticides and genetic technologies.

Caucasians, in particular, followed this pattern, which is in contrast with the Pew research (Pew Research Center, 2015a). However, people with certain characteristics tend to be more amenable to chemical and genetic technologies. The strongest pattern is perhaps seen in younger people, who are more likely to buy GMOs and products cultivated with chemicals than are older generations. This perhaps indicates a greater acceptance of newer technologies in general amongst younger people. Men also largely follow this pattern, which may suggest mothers are more cautious with children, though our data paradoxically show children being positively correlated with willingness to buy GMO foods grown with insecticides and fungicides. It is unclear what may be leading to this pattern.

Similar to findings by Pew Research (Pew Research Center, 2015a, Pew Research Center, 2015b), consumers with advanced degrees tend to be more comfortable with these technologies. While advanced academic degrees will lead to greater acceptance, the present study also demonstrates the role that basic information can provide. When respondents were provided with definitions of what each technology and practice is (all information), they were more inclined to buy GMO foods or those produced through CRISPR. In addition, people were less likely to purchase organic foods if they were provided GMO, GMO and CRISPR, and pesticide information. Taken together this may show that people are more uneasy with the stigma that certain ‘buzzwords’ (e.g., GMO) elicit than with the actual technologies themselves once they become familiar with the definition of these terms. Thus, providing this information to consumers, such as through labeling programs, may do much to alleviate their concerns. As CRISPR and other gene-editing technologies become refined and more widely used in food production, this advice seems especially pertinent in order to avoid the perception problems that have plagued genetic modification and chemical pesticides over the past decades.

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A Case Study Approach to Evaluate Economic Costs and Benefits of Winter Cover Crop Adoption in Arkansas Furrow-Irrigated Rice–Soybean Rotation

Divya Kandanool, Rachna Tewari, V. Steven Green, and Joseph Massey

This study examines the economics of three rice cropping systems: furrow-irrigation with winter cover crops (FRCC), furrow-irrigation without cover crops (FRNCC), and multiple-inlet rice irrigation (MIRI) serving as the rice control, followed by soybeans with (SBCC) and without cover crops (SBNCC) for two locations in Arkansas during 2019-2020 (Burdette) and 2020-2021(Walcott). Net returns at Burdette were higher in FRNCC, 2019 and SBNCC, 2020. Net returns were higher at Walcott in MIRI, 2020 and SBCC, 2021. The cost-benefit ratio was higher for soybean than rice. Partial budgets revealed positive net effects for changing from MIRI to FRNCC at Burdette, and for changing from FRNCC to FRCC at Walcott. Sensitivity analysis of the total seed, cover crop seed, herbicide, and fertilizer costs revealed that profit margins for both rice and soybeans were stable with few minor exceptions at one location.

Key words*:* Enterprise Budget, Furrow-irrigated rice, Partial Budget, Profitability, Sensitivity Analysis, Winter Cover Crops

The practice of furrow-irrigating rice (*Oryza sativa*), also known as row rice or furrow-rice, is increasing in the mid-south. U.S. farmers grow furrow-irrigated rice to avoid labor costs associated with the installation and removal of levees and levee gates needed for flood rice production (Stevens, Rhine, and Heiser, 2018; Vories, Counce, and Keisling, 2002). Furthermore, growing rice on raised beds as is done in furrow-irrigated rice has an added advantage of providing greater flexibility in addressing changing markets and weather conditions since the beds can also be used to grow other row crops, reduce, or eliminate fall tillage, and allow more timely planting of soybean (*Glycine max Merr.*) in wet springs (Karki et al., 2021). The raised beds of furrow-irrigated rice systems have also opened the possibility of growing cover crops in rice which would otherwise be quite challenging in poorly drained soils typical of mid-south rice production areas.

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In the United States, cover crop use in row crops like soybean and corn (*Zea mays L.*) is growing due to multiple agronomic and environmental benefits observed (Bergtold et al., 2019; Blanco-Canqui et al., 2015). Similarly, cover crop use in furrow-irrigated rice could be helpful, especially if cover crops reduce water demand, reduce soil erosion, stabilize the raised beds over the wet winter season, and suppress the problem of glyphosate-resistant pigweed (*Palmer amaranth*). Winter cover crop use in rice production may reduce or eliminate the impacts of intensive tillage and could improve biological, chemical, and physical soil properties (Nascente and Stone, 2018). A 1:1 soybean–rice rotation is a typical rotation used in Arkansas (AR) as rotations with soybean after rice reduced weed pressure in rice leading to reduced production costs (Watkins, Anders, and Windham, 2004).

The potential for yield increases due to increased soil fertility, weed suppression and irrigation efficiency have increased cover crop adoption (Bergtold et al., 2019). While cover crop adoption grew by 50% from 4,168,262 hectares in 2012 to 6,232,159 hectares in 2017. according to the 2017 U.S. Department of Agriculture (USDA) Census of Agriculture, adoption rates varied significantly across the United States. (LaRose and Myers, 2019) and are still not prominent among most agricultural producers (Kirkpatrick, 2021; Nielsen et al., 2016; Olson et al., 2014). A major barrier for cover crop adoption is the upfront costs often associated with their use (Snapp et al., 2005; Tellatin and Myers, 2018). Ultimately, increased management requirements, new equipment purchases, and lack of program support may discourage adoption (Bergtold et al., 2019). Analysis of the costs and benefits of cover crops on long-term farm profitability are needed to make a financial decision while adopting cover crops.

In order to implement conservation management practices such as cover crops, farmers must make necessary adjustments to their farms to ensure economic profitability and efficient management operations. Farmers often face decisions regarding their farming practices, which can either be aimed at improving their financial gains or mitigating the impacts of adverse conditions such as fluctuations in market conditions. Such decisions can range from straightforward choices among alternatives within a particular enterprise to complicated ones that require a complete transformation of the business and its enterprises (Soha, 2014). Alternative management choices within a farm enterprise can have different impacts on the profitability. Selecting the optimal alternative can determine whether an enterprise makes a profit or suffers a loss. Various budgeting tools such as enterprise and partial budgeting, and sensitivity analysis are utilized in agriculture to plan production inputs and outputs (Soha, 2014).

Cover crop use is associated with direct and indirect costs, opportunity costs, risk, and agricultural policy considerations. Planting, managing the cover crop, and investing in no-till drills or planters to establish the cover crops are some of the direct costs associated with adoption (Bergtold et al., 2019). Indirect costs of adoption can occur due to two possibilities: 1. Delaying stand establishment of the succeeding cash crop (due to nitrogen (N) immobilization in the soil and lowered soil temperature). 2. Management of cover crops (when a successful cover crop stand is attained) that are hard to terminate and compete with the cash crop (Snapp et al., 2005). The opportunity cost of income foregone (potential revenue from harvesting) from cash crops is the biggest cost associated with cover crop adoption as the producers think it is irrational to spend the time and money in planting and terminating a cover crop. They need to invest time, effort, and money in planting and terminating cover crops, which takes away from the resources that could be dedicated to cash crops. As a result, they see cover crops as a cost because they believe the potential revenue from cash crops is being left unharvested in the field. Opportunity costs of time and money indirectly contribute to costs of cover crops and are chief reasons that they are rarely grown during periods when cash crop alternatives are feasible (Bergtold et al., 2019). Every producer's situation is unique, and it also applies to their experience with cover crops depending on the management, soil type, and weather. However, cover crops may decrease production costs of the following cash crop by reducing fertilizer, herbicide, and pesticide applications. A combination of hairy vetch *(Vicia villosa)* cover crop and an application of 168 kg N ha^{-1} was more profitable compared to 244 kg N ha^{-1} of applied N with no cover crop suggesting a reduction in fertilizer inputs from cover crop use in corn at Milan, TN (Larson et al., 1998). Lu et al., (2000), reported that cover crops with high biomass like cereal rye (*Secale cereale*) compete with weeds for nutrients and can reduce herbicide applications in the cash crop.

Currently, there is inadequate information regarding the economic performance of cover crops in furrow-irrigated rice. If winter cover crops offer potential net benefits of reducing erosion, improving soil health, water infiltration, and weed suppression this could be the foundation for developing subsidies that could support farmers (Snapp et al., 2005). We are aware of no studies that explicitly examine the economics of cover crop adoption in a furrow-irrigated rice cropping system. The overall goal of this study was to evaluate the impact of winter cover crops on the profitability of a furrow-irrigated rice-soybean rotation system. Specific objectives were to: (1) economically compare furrow-irrigated rice with cover crop (FRCC) and furrow-irrigated rice without cover crops (FRNCC) using multiple inlet rice (MIRI) as a control typical of the Lower Mississippi River Valley (LMRV), (2) compare the economics of soybean phase of rotation grown with cover crops (SBCC) and without cover crops (SBNCC) and (3) better understand incentives for and against cover crop adoption in a furrow-irrigated rice system.

Methodology

Our research was conducted at two locations in the state of Arkansas. One location was at Burdette, a town in northeastern Mississippi County. The second location was at Walcott, a town in Greene County. Walcott is ~93 kilometers (Km) away from Burdette, and the two locations differ in their soil types, management practices, and challenges. At these locations we compared the economics of three rice cropping systems and two soybean cropping systems that followed rice. The description of the research fields, year of study, soil type, cropping systems, and rotation, cropping history, and cover crops species used are described below.

Research location Burdette, AR (Year 2019-2020)

The research was conducted for two growing seasons, 2019 and 2020, on a commercial rice-soybean farm near Burdette, AR (35°49'8" N, 89°56'35" W). The soils at this location have been classified as Sharkey silty clay (Very fine, smectitic, thermic Chromic Epiaquerts) and Steele silty clay loam (Sandy over clayey, mixed, superactive, nonacid, thermic Aquic Udifluvents) soils, typical of the traditional rice producing soils in the Mississippi-Delta region. In 2019, three fields were studied: A ~30-ha field was planted with winter cover crops in the fall of 2018 followed by furrow-irrigated rice (FRCC) in 2019. The winter cover crop consisted of cereal rye, annual rye (*Lolium multiflorum*), black oat (*Avena strigosa*), and barley (*Hordeum vulgare*). The cover crop biomass averaged 2.96 ± 0.51 Mg ha^{-1} at the time of rice planting in 2019 (Table 1). After the rice harvest in 2019, a similar cover crop mixture was planted that was followed by soybeans (SBCC) in the 2020 growing season and the cover crop biomass averaged 2.87 ± 0.41 Mg ha^{-1} (Table 1). The second field (~27.5-ha) was planted with furrow-irrigated rice with no cover crops in the 2019 growing season (FRNCC) and soybeans with no cover crops in 2020 (SBNCC). The third field (~29.0-ha) served as the control field that was irrigated using Multiple Inlet Rice (MIRI), a flood rice system, in 2019. It was left fallow in 2020 and was not included in the soybean economic study. The seven-year cropping histories of each field is summarized in Table 1. All three fields were adjacent to one another. Hybrid rice (RiceTec XP753) was planted in all three rice systems. The soybean varieties Pioneer P46A86X and P48A32X were used in the SBCC and Pioneer P46A86X was planted in the SBNCC soybean systems.

Table 1. Cropping history of the research fields included in the economic study.

Location: Burdette, AR.					
	Field 1 (~30 ha)			Field 2 (~ 28 ha)	Field 3 (~29 ha)
Crop Year	**Cover Crop**	**Cover Crop Biomass (Mg ha^{-1})**	**Crop**	**Crop**	**Crop**
2012	-	-	Soybeans	Soybeans	Soybeans
2013	Wheat	-	Soybeans	Soybeans	Rice
2014	Wheat	-	Soybeans	Soybeans	Soybeans
2015	Wheat	-	Soybeans	Soybeans	Soybeans
2016	-	-	Rice	Rice	Rice
2017	-	-	Soybeans	Soybeans	Soybeans
2018	-	-	Soybeans	Soybeans	Soybeans
2019	Cover crop mix [1]	2.95	Rice	Rice	Rice
2020	Cover crop mix [2]	2.87	Soybeans	Soybeans	Fallow
Location: Walcott, AR.					
	Field 1 (~8 ha)			Field 2 (~ 8 ha)	Field 3 (~17 ha)
Crop Year	**Cover Crop**	**Cover Crop Biomass (Mg ha^{-1})**	**Crop**	**Crop**	**Crop**
2015	-	-	Soybeans	Soybeans	Soybeans
2016	-	-	Rice	Rice	Rice
2017	-	-	Soybeans	Soybeans	Soybeans
2018	-	-	Rice	Rice	Rice
2019	-	-	Soybeans	Soybeans	Soybeans
2020	Cover crop mix [2]	0.43	Rice	Rice	Rice
2021	Cover crop mix [3]	2.56	Soybeans	Soybeans	Soybeans

Field 1 – Planted as furrow rice with cover crops (FRCC) in 2019 and soybeans with cover crops (SBCC) in 2020. Field 2 – Planted as furrow rice without cover crops (FRNCC) in 2019 and Soybeans with no cover crops (SBNCC) in 2020. Field 3 – Planted as multiple inlet rice (MIRI) in 2019. [1] Cereal rye, annual rye, oats, and barley. [2] Black oat, cereal rye, winter wheat, crimson clover, and purple top turnip. [3] Wheat and crimson clover.

Research location Walcott, AR (Year 2020-2021)

This research was conducted on a commercial farm enterprise near Walcott, AR (36˚2' 42" N, 90˚ 42' 54" W) for the growing seasons of 2020 and 2021. At Walcott, the research site had three fields (Table 1), field 1 was on Calhoun silt loam (Fine-silty, mixed, active, thermic Typic Glossaqualfs), which was planted with furrow-irrigated rice with cover crops followed by soybeans. Field 2, also consisting of the same soil type, was planted with furrow-irrigated rice cultivation without cover crops followed by soybeans. Field 3 is on Foley Bonn Complex (fine-silty, mixed, active, thermic Albic Glossic Natraqualfs) and Forestdale silty clay loam soils (fine, smectitic, thermic Typic Endoaqualfs) and was planted with rice and flood irrigated via multiple inlets. For the year 2020, field 1 measuring ~8-ha, was planted with winter cover crops mixture of black oat, cereal rye, winter wheat (*Triticum aestivum*), crimson clover (*Trifolium incarnatum*), and purple top turnip (*Brassica rapa*) that was followed by furrow-irrigated rice in 2020. The cover crop biomass averaged 0.43± 0.15 Mg ha^{-1} at the time of rice planting in 2020 (Table 1). After the rice harvest, on the same field, a mixture of wheat and crimson clover cover crops were planted in the fall of 2020 followed by soybeans (SBCC) in 2021 and the cover crop biomass averaged 2.56 ± 0.67 Mg ha^{-1}(Table 1). The second field measuring ~8-ha was planted with no cover crops and rice irrigated using furrows (FRNCC) as an alternative treatment in 2020, that was followed by a soybean crop with no cover crops (SBNCC) in 2020. The third field ~17-ha was planted with rice and flood irrigated via multiple inlets (MIRI) in 2020 which was followed by soybeans in 2021. The 2021 soybean crop following MIRI was not included in the economic study. The five-year cropping histories of each field is summarized in Table 1 and all three fields were located close together at Walcott, AR. A hybrid rice FP7521 from Rice Tech was used for all three rice systems, and Armor 4541 XFS soybean was used in the soybean phase of the rotation compared in this analysis.

Data Collection

For the economic analyses we obtained seasonal production reports provided by the producers. All of the necessary resources for production were identified, along with the rate of application and per unit cost. In instances where producers did not provide information on fixed costs, such as machinery, and irrigation, we incorporated the average price per hectare from the University of Arkansas Extension budgets (Baker et al., 2020; Watkins, 2021) for the corresponding year into our calculations. We used these individual crop budgets to evaluate the main costs and benefits associated with growing a furrow-irrigated rice with and without winter cover crops and compared those systems to a flood rice system (multiple inlet rice, MIRI) for the year 2019 (Burdette) and for the year 2020 (Walcott). Similarly, we compared the rotation phase of soybean with cover crops to soybean without cover crops for the year 2020 (Burdette), and 2021 (Walcott) following rice production (Figure 1). We focused on expenditures incurred for machinery, planting, weed and pest management, cash crop seed, cover crop seed, labor, fuel, and fertilizer. Similarly, the benefits analyzed include cost reductions associated with reduced management inputs and increased revenue from better yields compared among the rice-soybean rotation systems. The benefits of improved soil properties and functions, increased soil organic matter content, and successive impacts on water management were not captured in these budget analyses as they had no incentives paid for the implementation of conservation practices.

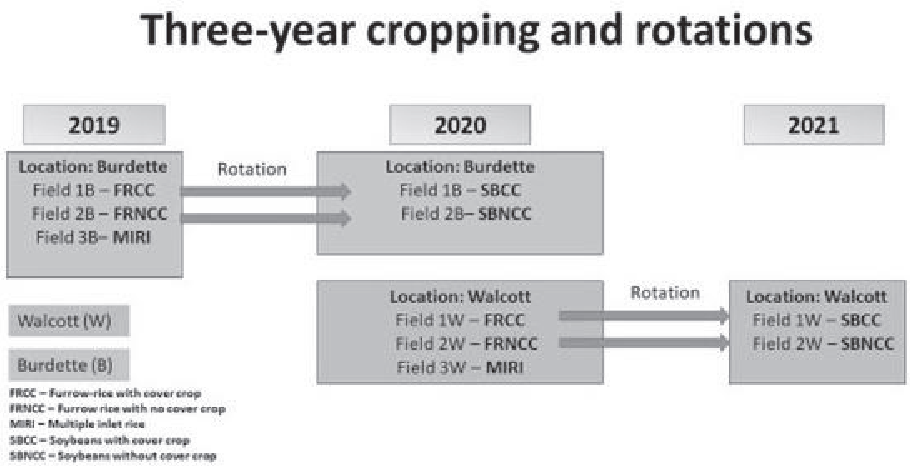

Figure 1. A schematic image showing the three-year cropping (2019, 2020, and 2021) systems and rotations for both Burdette and Walcott locations in AR.

Enterprise Budgeting Analysis

Agricultural market prices and management costs associated with rice and soybean production serve as a basis for analyzing the economic viability of the rice-soybean rotation systems discussed. Enterprise budgeting lists out income and costs of producing one enterprise (treatment fields) included in the study in a particular manner to provide an estimate of its profitability and facilitate comparisons among alternative enterprises (Riggs et al., 2005; Sharp Rod and Kaan, 2001). Hence, the enterprise budgets were developed to identify and compare profits of different enterprises within the same farm i.e., FRCC, FRNCC, and MIRI for 2019 and 2020 growing seasons at Burdette and Walcott locations respectively. After the rice crop, the rotation of soybeans SBCC, and SBNCC in 2020 (Burdette) and 2021(Walcott) were studied.

For each enterprise budget, the income and costs were grouped into crop revenue (from yield), operating expenses, and fixed expenses as per Riggs, Curtis, and Harris, (2005). The production report obtained from the producers includes information regarding input prices of fertilizers and herbicides, seed cost (cash and cover crop seed), and operating services like cultivating furrows, construction and removal of levees, irrigation, spraying, planting, harvesting, etc., are grouped under operating expenses. Equipment cost, land lease, storage, and labor are grouped under fixed expenses. An enterprise budget was constructed with input prices reported in US dollars on a per hectare basis and compared among treatment fields for the years 2019-2020 and 2020-2021 at both locations (Flanders, 2016). Each budget component in the production reports obtained from the producer was quantified for the entire field for each cropping system, which was later divided by the total area of the field to obtain the input values per hectare. Enterprise budgets were developed to have a combined representation of the costs and benefits of the management practice. Separate budgets were prepared for each crop to focus on crop-specific management practices. Figures S1 and S2 (Appendix A) show an example of prepared enterprise budgets of furrow-irrigated rice with cover crops (year 2019, Burdette, AR) and soybeans with cover crops (year 2020, Burdette, AR) for reference. After the budgets were prepared, a benefit-cost ratio was calculated for each cropping system that measures the potential benefits of a cropping system or investment against its cost. It is calculated by dividing the potential benefits of a cropping system by its total costs (Jones, 1982); the formula is as follows:

(1) Benefit-cost ratio = Value of net returns/Value of costs

A higher benefit-cost ratio greater than 1 indicates a greater rate of return on the investment, suggesting that the cropping system is financially viable and may be worth adopting (Jones, 1982).

Partial Budgeting

In addition to enterprise budgets, we focused on capturing the economic benefits and costs associated with utilizing cover crops in a furrow-irrigated rice-soybean rotation system using a partial budgeting tool. Partial budgeting is used to evaluate the expenses and benefits associated with a specific alternative management practice in a farming enterprise. It focuses only on the implications of the proposed alternative (such as adopting cover crops or choosing furrow-irrigated rice instead of flood irrigated rice) on farming operations by comparing the benefits and costs of implementing the alternative with those of the current practice unlike enterprise budget that lists all the costs and benefits of the entire enterprise to estimate its profits (Kay et al., 2008; Soha, 2014). Alternative cropping systems are explored as potential alternatives to conventional cropping methods to address various challenges such as environmental sustainability, resource efficiency, and resiliency. These systems often involve different approaches to crop management practices and planting techniques. It is essential to assess the feasibility, economic viability, and potential challenges associated with implementing these alternative cropping systems on a case-by-case basis.

A partial budget was prepared to determine the effect on the net returns of substituting one cropping system with an alternative system, without any significant changes in the entire farmland and technology (Plastina et al., 2018). Four partial budgets were prepared for each location, and the following alternatives were considered: 1. The adoption of furrow-irrigated rice with cover crops (FRCC) as an alternative to furrow-irrigated rice without cover crops (FRNCC) 2. The adoption of furrow-irrigated rice without cover crops (FRNCC) as an alternative to multiple inlet rice (MIRI-a flood type rice) 3. The adoption of furrow-irrigated rice with cover crops (FRCC) as an alternative to multiple inlet rice (MIRI-a flood type rice). 4. The adoption of soybean with cover crops (SBCC) as an alternative to soybean without cover crops (SBNCC). We considered costs of cover crop seed, planting, increased or decreased herbicide cost, increased or decreased fertilizer cost management practices and benefits like increased or decreased yields proposed by Plastina et al. (2018), to establish our criteria for the partial budgets. In this study, we analyzed the differences in revenue from yield and differences in operating costs including labor, fertilizers, herbicides, irrigation, and cover crop seed for each of the proposed alternatives.

Sensitivity Analysis

Sensitivity analysis is a method for studying how uncertainty in the output of a model can be attributed to different sources of uncertainty in the model input. Sensitivity analysis emphasizes the importance of understanding the relationship between input and output variables in a model, and how changes in input values can affect the model's output. Sensitivity analysis is a crucial tool for assessing the quality and reliability of models, particularly in complex systems where multiple sources of uncertainty may be present (Saltelli et al., 2007).

An analysis was performed to assess the strength of the baseline economic performance indicators (profit margin and gross margin) on future prices and identify which components were most influential on profit margins for the rice-soybean rotations investigated here. We simulated profit margin and total production cost scenarios to quantify the uncertainty in important cost estimates induced by adopting an alternative production practice. Sensitivity analysis was conducted to assess the uncertainty associated with selected cost variables. Hence, eight scenarios were developed for direct operational costs of the cash crop and cover crop seeds. Additionally, 10 scenarios investigating the impacts of herbicide and fertilizer costs were considered in order to capture the uncertainty of direct operating costs of the Arkansas rice-soybean production systems. The following scenarios were considered in response to possible future changes that can impact the adoption costs and profitability of the rice-soybean practices:

1. An increase of 20%, 15%, 10%, and 5% in total seed cost, and cover crop seed cost.
2. A decrease of 20%, 15%, 10%, and 5% in total seed cost, and cover crop seed cost.
3. An increase of 100%, 75%, 50%, 25% and 10% in herbicide and fertilizer cost.
4. A decrease of 100%, 75%, 50%, 25% and 10% in herbicide and fertilizer cost.

These scenarios are considered to predict risks associated with change in any of the cost estimates that can influence the profitability of utilizing winter cover crops in a rice or soybean system (Wei, Khachatryan, and Rihn, 2020). The sensitivity analysis of fertilizer management was not considered for soybeans at Burdette, as the producers did not apply any nitrogen, phosphorous (P) or potassium (K) fertilizer for the soybean crop. At Walcott, the sensitivity analysis of fertilizer management was considered as the producers applied P and K fertilizer for soybeans. Net income (profit), gross margin, and profit margin were calculated using the following formulas:

(2) Gross margin = (Total Sales – Total Costs)/Total Sales

(3) Net Income = Total Sales – Total Costs

(4) Profit Margin = (Net Income/Total Sales) *100

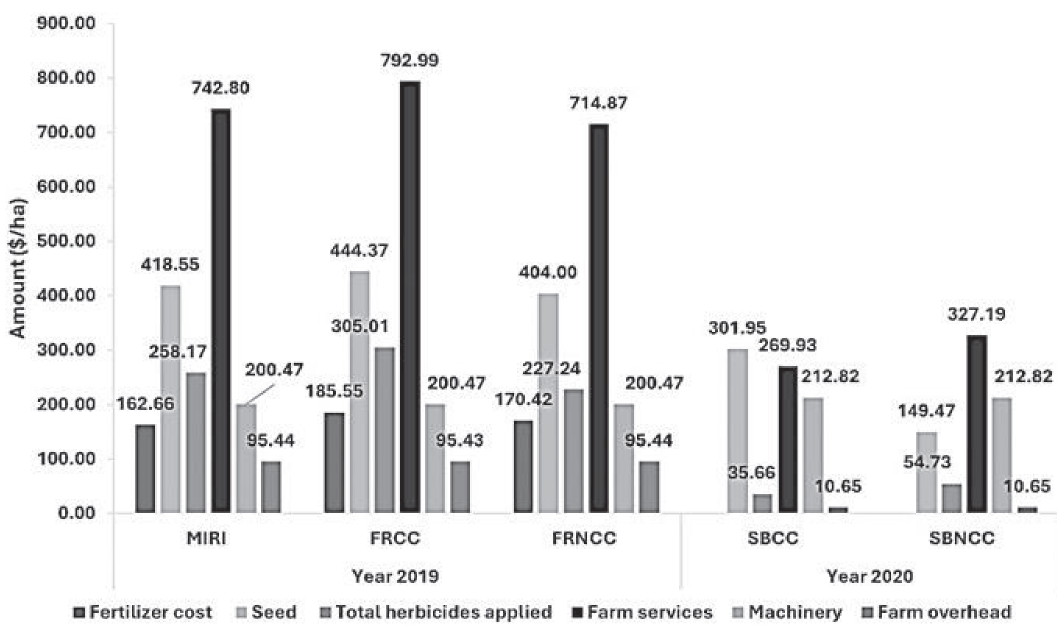

Figure 2. Comparison of total production costs ($ ha-[1]) for a rice-soybean rotation where rice was grown in 2019 followed by soybean in 2020 at Burdette, AR. The rice was irrigated using furrow-irrigation with (FRCC) and without winter cover crops (FRNCC) compared directly to rice grown using levees and multiple inlets (MIRI). The succeeding soybean crop was grown using furrow-irrigation with (SBCC) and without winter cover crops (SBNCC).

Results

Research location Burdette, AR (Year 2019-2020)

Enterprise Budgeting Analysis: A comparative analysis of expenditures incurred for MIRI, FRNCC, FRCC rice production in 2019 followed by SBCC and SBNCC soybean rotation in 2020 is presented in Figure 2. Seed costs were lowest in FRNCC at \$404.00 ha^{-1}, followed by MIRI at \$418.55 ha^{-1} and FRCC at \$444.37 ha^{-1}. The FRCC incurred a higher seed cost due to the additional cost of cover crop seed; this was also true for the SBCC system where seed costs were \$301.95 ha^{-1}. The seed cost for SBNCC was \$ 149.77 ha^{-1}. Fertilizer costs for both MIRI and FRNCC systems of rice production were similar with \$162.66 ha^{-1} and \$170.42 ha^{-1}, respectively, while the FRCC system incurred a slightly higher fertilizer cost of \$185.55 ha^{-1} due to a high fertilizer rate needed to compensate for the reduced N availability that can occur due to immobilization early in the season after cover crop termination. The total herbicide costs for FRCC were higher at \$305.01 ha^{-1} compared to FRNCC at \$227.24 ha^{-1} and MIRI at \$258.17 ha^{-1}. In 2020, the herbicide cost for SBCC and SBNCC was \$35.66 ha^{-1} and \$54.73 ha^{-1}, respectively which was much lower compared to the rice production and thus increases the profitability of the enterprise due to the adoption of soybean in the rotation.

The FRNCC incurred a lower cost of \$714.87 ha^{-1} for farm services compared to MIRI at \$742.80 ha^{-1} due to the additional services needed for levee plowing, levee splitting and removal and FRCC at \$792.99 ha^{-1} due to additional services for airplane spraying of herbicides and spreading fertilizer. Adopting cover crops into a cropping system requires additional management associated with planting and termination which explains the higher cost of farm services due to the additional trips made to the field. Compared to the rice crop in 2019, SBCC and SBNCC incurred low expenditures of \$269.93 ha^{-1} and \$327.19 ha^{-1} respectively for farm services. Low farm service expenditures are an advantage of rotating soybeans with furrow-irrigated rice, as the raised beds of furrow-irrigated rice can be reused to grow soybeans. The soybean field planted with cover crops for SBCC compared to the no cover field had difference in services expenditure incurred to reshape and maintain the beds between the SBCC and SBNCC at \$269.93 ha^{-1} and \$327.19 ha^{-1}, respectively. There is not much difference in the cost incurred by machinery and farm overhead charges within the three rice systems (FRCC, FRNCC and MIRI) and two soybean systems (SBCC and SBNCC).

The adoption of FRNCC resulted in an average yield of 14.21 Mg ha^{-1} which is comparable to the MIRI 14.19 Mg ha^{-1} whereas FRCC comparatively yielded lower, 10.49 Mg ha^{-1}, approximately 26% lower than the FRNCC and MIRI (Table 2). In 2020, the SBCC crop yielded 4.52 Mg ha^{-1} and the SBNCC yielded 5.13 Mg ha^{-1} (Table 2). The advantage of FRNCC was seen as a case of reduced production cost per hectare with a yield advantage compared to MIRI. The adoption of FRNCC resulted in a lower cost of cultivation \$1448.08 ha^{-1} compared to the MIRI \$1512.09 ha^{-1}. The cost of cultivation increased to \$1654.18 ha^{-1} to adopt FRCC compared to MIRI's \$1512.09 ha^{-1}. The net returns per hectare were higher in FRNCC at \$1219.85 ha-[1] than the MIRI at \$1152.06 ha^{-1} and FRCC at \$269.68 ha^{-1} with a benefit-cost ratio of 0.84, 0.76, and 0.16 for FRNCC, MIRI, and FRCC rice systems, respectively. For the soybean rotation year, the cost of cultivation was lower for SBCC at \$410.42 ha^{-1} compared to SBNCC at \$508.87 ha^{-1}. The net returns per hectare were slightly higher in SBNCC at \$1632.37 ha^{-1} than in SBCC at \$1516.28 ha^{-1} with a benefit-cost ratio of 3.69 and 3.21 for SBCC, and SBNCC soybean systems, respectively.

Table 2. Comparative economics of row-rice with cover crops (FRCC), row-rice with no-cover crops FRNCC, and Multiple Inlet Rice (MIRI) in 2019, followed by soybean rotation in 2020 at Burdette, AR.

	2019			2020	
Particulars	**FRCC**	**FRNCC**	**MIRI**	**SBCC**	**SBNCC**
Yield (Mg ha^{-1})	10.49	14.21	14.19	4.52	5.13
Gross Revenue (\$ ha^{-1})	2055.34	2783.66	2781	1537.24	1725.45
Cost of cultivation (Variable costs; \$ ha^{-1})	1654.18	1448.08	1512.09	410.42	508.87
Total Costs (\$ ha^{-1})	1785.66	1563.82	1628.94	20.96	93.08
Net returns (\$ ha^{-1})	269.68	1219.85	1152.06	1516.28	1632.37
Benefit-cost ratio	0.16	0.84	0.76	3.69	3.21

Benefit-cost ratio = Value of net returns/Value of costs. FRCC – Furrow rice with cover crops. FRNCC – Furrow rice without cover crops. MIRI – Multiple inlet rice. SBCC – Soybeans with cover crops. SBNCC – Soybeans without cover crops.

Partial Budgeting Analysis: Partial budgeting analysis of MIRI vs FRNCC shows that with the adoption of a furrow-irrigated rice system with no cover crops, producers have the benefit of reduced costs associated with labor, fuel, irrigation, and farm services while the expenditure increased on fertilizer and herbicide applications as well as crop protection costs (Table 3). This may be due to the challenges associated with managing weeds due to the lack of flood in the furrow-irrigated rice. The adoption of FRNCC also resulted in a profit of \$290.04 ha^{-1}. The partial budgeting analysis of MIRI vs FRCC (Table 3) indicated a net economic loss of \$562.71 ha^{-1} of FRCC system. The expenditure increased on fertilizer and herbicide applications as well as crop protection costs for FRCC to compensate for N unavailability and to control weeds. The partial budget for FRNCC vs FRCC (Table 3) indicates a net economic loss of \$235.56 ha^{-1} for FRCC. The partial budget for SBNCC vs SBCC (Table 4) indicates a net profit of \$48.81ha^{-1} for SBCC.

Table 3. Partial budget analysis comparing the three rice systems with an alternative production plan (or a proposed change of plan) at Burdette, AR.

	Existing production plan compared to the proposed change		
	MIRI to FRNCC	**MIRI to FRCC**	**FRNCC to FRCC**
Positive Effects		**Amount ($ ha^{-1})**	
a. Increased revenue (from adopting an alternative)	2778.85	2051.79	2051.79
b. Decreased costs (from not adopting current practice)			
Labor cost	83.2	83.2	83.2
Fuel cost	44.13	44.13	38.77
Irrigation cost	92.76	92.76	109.04
Farm services	489.67	489.67	452.61
Fertilizer cost	-	-	170.42
Total positive effects	3488.61	2761.55	2905.83
Negative Effects		**Amount ($ ha^{-1})**	
a. Decreased revenue (from not adopting current practice)	2776.18	2776.18	2778.16
b. Increased costs (from adopting an alternative)			
Fertilizer cost	170.42	185.54	-
Herbicide application cost	227.23	304.99	304.99
Crop protection cost	24.73	24.73	24.73
Cover crop seed cost	-	32.81	32.81
Total negative effects	3198.57	3324.26	3141.39
Profit (Total positive - negative)	**290.04**	**-562.71**	**-235.56**

FRNCC – Furrow rice without cover crops. FRCC – Furrow rice with cover crops. MIRI – Multiple inlet rice.

Table 4. Partial budgeting for soybean without cover crop (SBNCC; an existing soybean production plan) *vs* soybean with cover crop (SBCC; a proposed change of plan) at Burdette, AR.

Positive Effects	**Amount ($ ha^{-1})**	**Negative Effects**	**Amount ($ ha^{-1})**
a. Increased revenue (From adopting SBCC)	1534.58	a. Decreased revenue (From not adopting SBNCC)	1722.46
b. Decreased costs (From not adopting SBNCC)		b. Increased costs (From adopting SBCC)	
Farm services	289.1	Herbicide application cost	35.66
		Cover crop seed cost	16.75
Total positive effects	1823.68	Total negative effects	1774.87
Profit (Total positive - negative)	48.81		

SBCC – Soybeans with cover crops. SBNCC – Soybeans without cover crops.

Table 5. Economic performance indicators for three different rice systems and two soybean rotation systems at Burdette, AR.

					Economic Performance Indicator		
Year	**Production Practice**	**Total Sales ($ ha^{-1})**	**Total Costs ($ ha^{-1})**	**Total Operating Expenses ($ ha^{-1})**	**Net income [a] ($ ha^{-1})**	**Profit margin [b] (%)**	**Gross margin [c] (%)**
2019	MIRI	2776.17	1626.12	1509.46	1150.06	41.43	45.63
	FRCC	2051.79	1782.57	1651.32	269.21	13.12	19.52
	FRNCC	2779.55	1561.5	1445.93	1218.05	43.82	47.98
Year	**Production Practice**	**Total Sales ($ ha^{-1})**	**Total Costs ($ ha^{-1})**	**Total Operating Expenses ($ ha^{-1})**	**Net income [a] ($ ha^{-1})**	**Profit margin [b] (%)**	**Gross margin [c] (%)**
2020	SBCC	1534.58	20.93	409.71	1513.65	98.64	73.3
	SBNCC	1722.46	92.92	507.99	1629.54	94.61	70.51

*[a] Net income = total sales (returns or revenue) – total costs. [b] Profit margin = (net income (or profit)/total sales) *100. [c] Gross margin = total sales - variable costs (operating costs)/total sales *100. FRCC – Furrow rice with cover crops. FRNCC – Furrow rice without cover crops. MIRI – Multiple inlet rice. SBCC – Soybeans with cover crops. SBNCC – Soybeans without*

To summarize, it is apparent that adopting a furrow-irrigated rice system without cover crops would be profitable for the producers while the use of winter cover crops was less profitable in FRCC. The SBCC system was more profitable than the SBNCC system.

Sensitivity Analysis: Total costs and economic performance indicators of the three different rice and two soybean production systems are summarized in Table 5, and all three economic indicators suggest that all rice-soy rotation systems had positive economic returns. A cross-comparison between the gross and profit margin indicates which rice-soy rotation system is profitable. Among the three rice production systems, FRCC had the lowest gross and profit margins and the highest total production cost at 13.12%, 19.52%, and \$1782.57 ha^{-1}, respectively. For the soybean production year, SBNCC had lower gross and profit margins, and highest total production cost at 94.61%, 70.51%, and \$1722.46 ha^{-1}, respectively. For sensitivity analysis, we considered scenarios of profit margin and total production costs related to changes in costs induced by alternative production practices. In the furrow-irrigated rice-soy rotation system with cover crops, the cost of rice/soybean and cover crop seed can also impact the decisions of adopting cover crops into a cropping system. Figure 3a and 3b presents the results of sensitivity analysis associated with the total seed cost (cash crop and cover crop seed cost) varying between -20% and +20% with 5% incremental change. The total seed cost was more stable to fluctuations with less impact on the profit margin in FRNCC followed by MIRI, with FRCC being the least stable and least profitable among the three rice systems (Figure 3a). For both SBCC and SBNCC, the total soybean seed cost was also stable to fluctuations with SBNCC having slightly lower profit margin than SBCC (Figure 3b). The sensitivity associated with the cover crop seed cost varied between -20% and +20% with 5% incremental change. The analysis showed that profit margins for FRCC and SBCC were not significantly affected by the changes in cover crop seed costs owing to their limited share of total production costs (Figure 4a and 4b). Figure 5a and 5b show profit margins with scenarios indicating changes in herbicide cost for rice and soybean ranging from -100% to +100%. For the FRCC system, the change in herbicide cost had a large impact on the profit margin (-1.7%) for a 100% increase in herbicide cost scenario, while MIRI and FRNCC were stable (Figure 5a). The profit margin of SBCC and SBNCC systems also remained stable to fluctuations in herbicide cost (Figure 5b). Figure 6a shows change in fertilizer cost for rice ranging from -100% to +100% and the profit margin of FRCC was greatly impacted compared to FRNCC and MIRI.

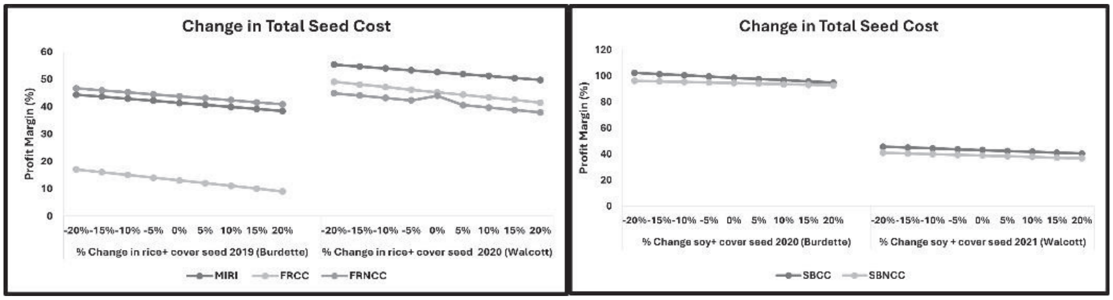

Figure 3. (a, left)) Results of the sensitivity analysis for profit margin scenarios simulated for rice crop with respect to total (rice + cover crop) seed cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to total (soy + cover crop) seed cost for Burdette and Walcott.

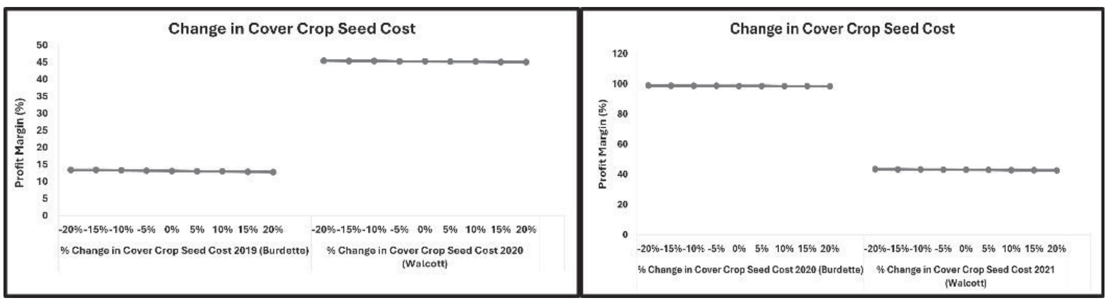

Figure 4. (a, left) Results of the sensitivity analysis for profit margin scenarios simulated for rice crop with respect to cover crop seed cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to cover crop seed cost for Burdette and Walcott.

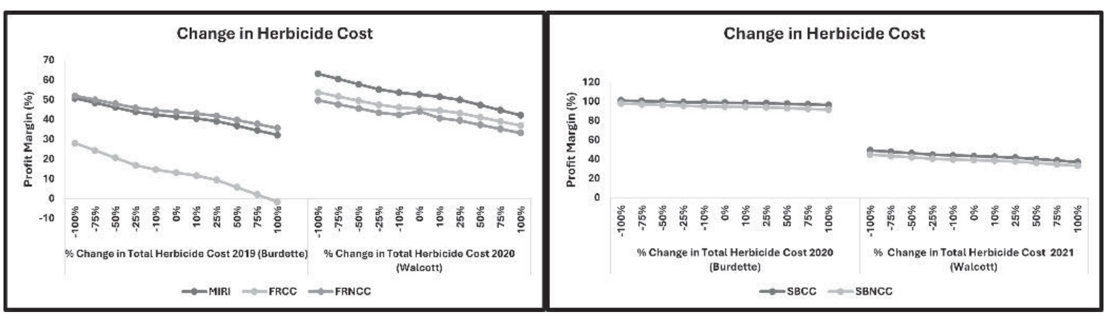

Figure 5. (a, left) Results of the sensitivity analysis for profit margin scenarios simulated for rice crop with respect to herbicide cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to herbicide cost for Burdette and Walcott.

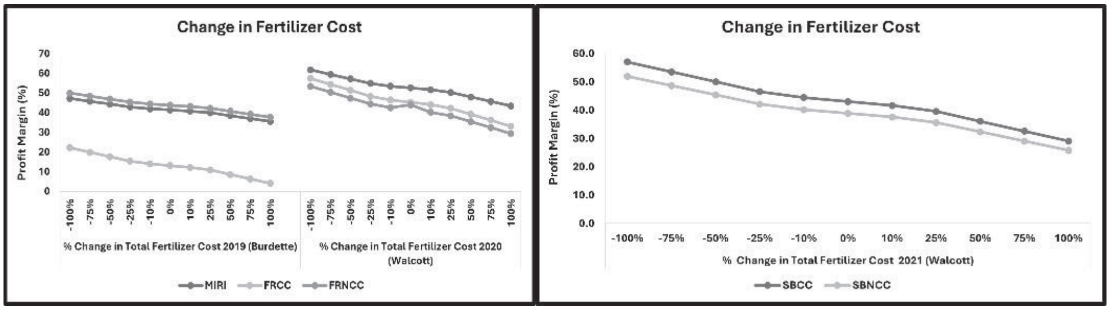

Figure 6. (a, left) Results of the sensitivity analysis for profit margin scenarios simulated for rice crop with respect to fertilizer cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to fertilizer cost for Walcott.

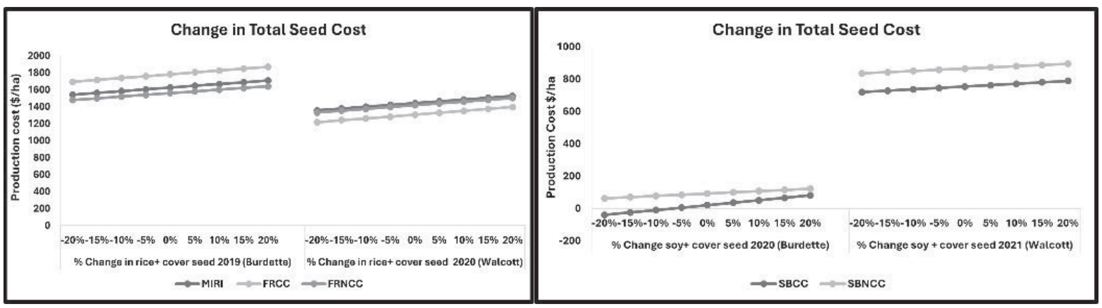

Figure 7. (a, left) Results of the sensitivity analysis for total production cost scenarios simulated for rice crop with respect to total (rice + cover crop) seed cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to total (soy + cover crop) seed cost for Burdette and Walcott.

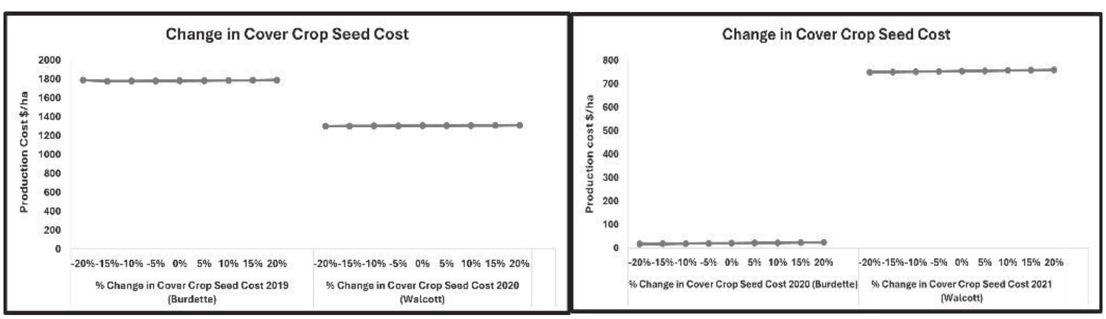

Figure 8. (a, left) Results of the sensitivity analysis for total production cost scenarios simulated for rice crop with respect to cover crop seed cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to cover crop seed cost for Burdette and Walcott.

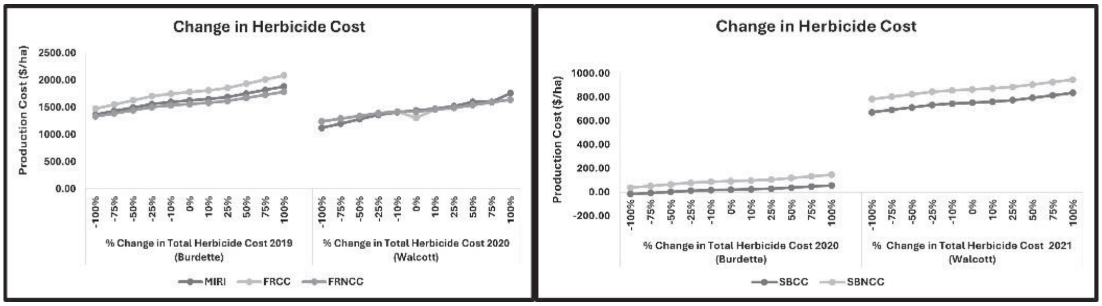

Figure 9. (a, left) Results of the sensitivity analysis for total production cost scenarios simulated for rice crop with respect to herbicide cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for profit margin scenarios simulated for soybean crop with respect to herbicide cost for Burdette and Walcott.

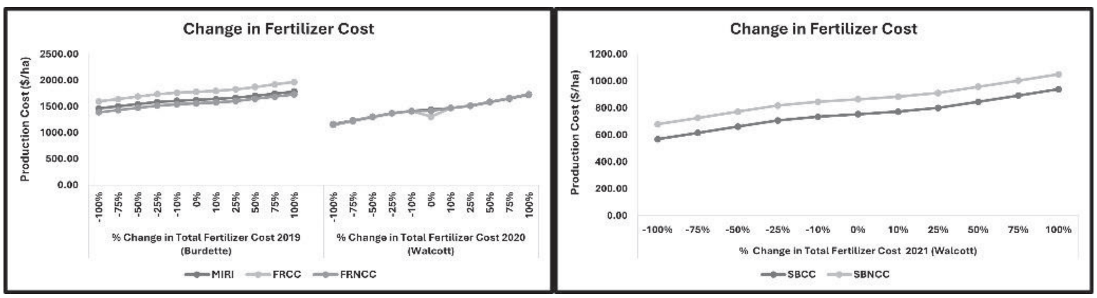

Figure 10. (a, left) Results of the sensitivity analysis for total production cost scenarios simulated for rice crop with respect to fertilizer cost for Burdette and Walcott. (b, right) Results of the sensitivity analysis for total production cost scenarios simulated for soybean crop with respect to fertilizer cost for Walcott.

The sensitivity analysis in Figure 7a and 7b demonstrates the relationship between the total production cost and the total seed cost, including both cash crop and cover crop seed expenses. Interestingly, fluctuations in the total seed cost do not exert a significant impact on the production costs overall. However, the production costs for FRCC exhibit the highest values, followed by MIRI, and FRNCC. The analysis revealed a significant sensitivity of production costs to the total seed cost specifically in soybean, particularly in the case of SBCC. Notably, a reduction of 20%, 15%, and 10% in the total seed cost resulted in cost reductions of -\$39 ha^{-1}, -\$24 ha^{-1}, and -\$9 ha^{-1}, respectively (Figure 7b). These findings highlight the potential cost-saving benefits associated with lowering the total seed cost in SBCC. Figure 8a and 8b suggest that variations in cover crop seed costs had minimal influence on production costs, indicating that changes in cover crop seed costs did not significantly affect production costs or profit margins. On the other hand, the sensitivity analysis presented in Figure 9a and 9b illustrates the relationship between production costs and fluctuations in herbicide costs for rice and soybean crops. For the FRCC system, a 100% reduction in herbicide cost led to a 17% decrease in production costs, while a 100% increase in herbicide cost resulted in a 15% increase in production costs. These findings emphasize the substantial impact that changes in herbicide costs can have on production costs within the FRCC system. Continuing with the analysis of the soybean phase within the rotation, it was observed that a 100% reduction in herbicide costs resulted in a significant decrease in total production costs by -$14.73 per hectare, while a 75% reduction in herbicide costs led to a reduction of -$5.81 per hectare (Figure 9b). These findings demonstrate that soybean rotation after rice crop decrease the cost of production and increases profitability overall. The variations in fertilizer costs had a uniform impact across all three rice systems, resulting in a 10% increase or decrease in production costs (Figure 10 a). These findings illustrate potential future possibilities and risks that producers may face regarding their production costs.

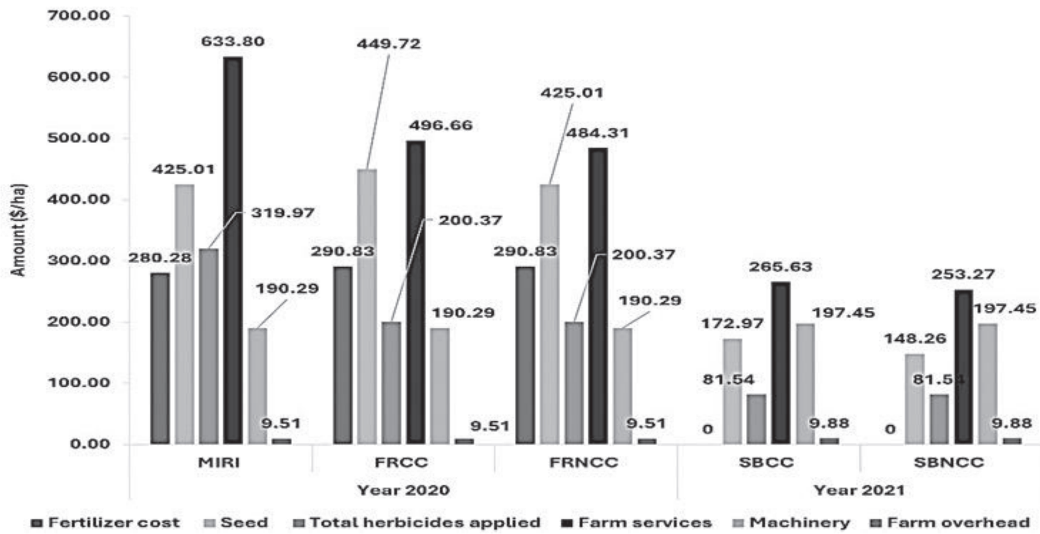

Figure 11. Comparison of total production costs ($ ha-^{1}) for a rice-soybean rotation where rice was grown in 2020 followed by soybean in 2021 at Walcott, AR. The rice was irrigated using furrow-irrigation with (FRCC) and without winter cover crops (FRNCC) compared directly to rice grown using levees and multiple inlets (MIRI). The succeeding soybean crop was grown using furrow-irrigation with (SBCC) and without winter cover crops (SBNCC).

Research location Walcott, AR (Year 2020-2021)

Enterprise Budget Analysis: A comparative analysis of expenditure incurred on various inputs for MIRI, FRNCC, FRCC rice production in 2020 followed by SBCC and SBNCC soybean rotation in 2021 is presented in Figure 11. The expenditure incurred on seed in FRNCC, and MIRI were the same at $425.01 ha^{-1}, compared to FRCC at $449.72 ha^{-1}. The FRCC incurred a higher seed cost due to the additional cost of cover crop seed. Similarly, seed cost for the SBCC system was $172.97 ha^{-1} versus $148.26 ha^{-1} for SBNCC. The costs incurred on fertilizer were the same for both FRCC and FRNCC at

\$290.83 ha^{-1} and slightly higher than MIRI at \$280.83 ha^{-1}. This was because furrow-irrigated rice systems need more nitrogen to compensate for N-losses due to lack of flood. This is a common management practice for furrow-irrigated rice among producers. Total herbicide costs incurred for FRCC and FRNCC were similar at \$200.37 ha^{-1} compared to the MIRI at \$319.97 ha^{-1}. In 2021, the herbicide cost for SBCC and SBNCC was \$ 81.54 ha^{-1} which was approximately 58% lower than rice herbicide cost in 2020.

The FRNCC incurred a lower cost of \$ 484.31 ha^{-1} for farm services followed by FRCC at \$ 496.66 ha^{-1}, and MIRI at \$633.80 ha^{-1}. This was because the furrow irrigated rice system uses minimum or no tillage and does not require construction and pulling down of levees and requires minimum maintenance services compared to MIRI. Adopting cover crops into a cropping system needs additional management of planting and terminating cover crops before the growing season which can explain the slightly higher cost of farm services for FRCC compared to FRNCC.

There was no variation in the costs incurred by machinery and farm overhead charges within the three rice and two soybean systems as these values were obtained from the University of Arkansas Rice and Soybean Budgets 2020 (Baker et al., 2020) as they were not captured in the producer's production reports. The adoption of furrow-irrigation with cover crops in rice did not have any significant difference in yields compared to furrow-irrigated rice without cover crops. The rice yields were 12.66 Mg ha^{-1} and 12.18 Mg ha^{-1} for FRNCC and FRCC, respectively. Comparatively, MIRI yielded 15.53 Mg ha^{-1}, which is approximately 20% more than the two furrow-irrigated systems (Table 6). In 2021, the SBCC crop yielded 3.90 Mg ha^{-1} and the SBNCC yielded 4.17 Mg ha^{-1} (Table 6). For this location, the advantage of FRCC was approximately 8% less cultivation cost per hectare (\$1291.56 ha^{-1}) compared to FRNCC (\$1402.95 ha^{-1}). Even though MIRI had the highest cost of cultivation (\$1402.95 ha^{-1}), MIRI had an advantage of higher yield that increased the net returns (\$1602.22 ha^{-1}). The net returns were slightly higher in FRCC (\$1083.66 ha^{-1}) than the FRNCC (\$1065.84 ha^{-1}). The furrow-irrigated rice system with cover crops (FRCC) proved to be slightly more profitable for this location with a benefit-cost ratio of 0.84 compared to FRNCC (0.76) but not more profitable than MIRI (1.08; Table 6).

For the soybean crop year, the cost of cultivation was lower for SBCC at \$557.97 ha^{-1} compared to SBNCC \$669.36 ha^{-1}, which resulted in higher net returns for SBCC (\$572.20 ha^{-1}) than SBNCC (\$552.40 ha^{-1}). The net returns and cultivation cost variables affected the benefit-cost ratios of SBCC (1.03) and SBNCC (0.83).

Table 6. Comparative economics of row-rice with cover crops (FRCC), row-rice with no-cover crops FRNCC, and Multiple Inlet Rice (MIRI) in 2020, followed by soybean rotation in 2021 for Walcott, AR.

	2020			2021	
Particulars	**FRCC**	**FRNCC**	**MIRI**	**SBCC**	**SBNCC**
Yield (Mg ha^{-1})	12.18	12.66	15.53	3.9	4.17
Gross Revenue	2392.57	2486.14	3047.52	1327.97	1419.55
Cost of cultivation (Variable costs; $ ha^{-1})	1291.56	1402.95	1479.94	557.97	669.36
Total Costs ($ ha^{-1})	1308.91	1420.3	1445.31	755.77	867.15
Net returns ($ ha^{-1})	1083.66	1065.84	1602.22	572.2	552.4
Benefit-cost ratio	0.84	0.76	1.08	1.03	0.83

Benefit-cost ratio = Value of net returns/Value of costs. FRCC – Furrow rice with cover crops. FRNCC – Furrow rice without cover crops. MIRI – Multiple inlet rice. SBCC – Soybeans with cover crops. SBNCC – Soybeans without cover crops.

Table 7. Partial budget analysis comparing the three rice systems with an alternative production plan (or a proposed change of plan) at Walcott, AR.

	Existing production plan compared to the proposed change		
	MIRI to FRNCC	**MIRI to FRCC**	**FRNCC to FRCC**
Positive Effects		**Amount ($ ha^{-1})**	
a. Increased revenue (from adopting an alternative)	2481.84	2388.44	2388.44
b. Decreased costs (from not adopting current practice)			
Labor cost	24.71	24.71	19.77
Fuel cost	-	-	-
Irrigation cost	172.97	172.97	148.26
Farm services	460.84	460.84	336.05
Fertilizer cost	-	-	290.83
Total positive effects	3140.35	3046.95	3183.5
Negative Effects		**Amount ($ ha^{-1})**	
a. Decreased revenue (from not adopting current practice)	3042.25	3042.25	2481.84
b. Increased costs (from adopting an alternative)			
Fertilizer cost	290.83	290.83	-
Herbicide application cost	200.37	200.37	200.37
Crop protection cost	-	-	24.71
Cover crop seed cost	-	24.71	-
Total negative effects	3533.46	3558.17	2706.92
Profit (Total positive - negative)	**-393.11**	**-511.22**	**476.43**

FRNCC – Furrow rice without cover crops. FRCC – Furrow rice with cover crops. MIRI – Multiple inlet rice.

Partial Budgeting Analysis: Partial budgeting analysis of MIRI as the current practice compared to the intended change to FRNCC resulted in net negative effect of $393.11 ha^{-1} (Table 7). The partial budgeting analysis of MIRI changing to FRCC indicated a net economic loss of $511.22 ha^{-1} (Table 7). However, the analysis shows that with the adoption of FRCC, producers have the benefit of reduced labor, irrigation, and farm services cost just like the FRNCC system except for the increase in seed cost due to cover crop seed. The partial budget for a current practice of FRNCC intended to change to

FRCC (Table 7) indicates a net positive effect of \$476.43 ha^{-1}. In this comparison the FRCC had the advantage of reduced costs and no significant yield differences compared to FRNCC. The partial budget for SBNCC changing to SBCC (Table 8) indicates a net positive effect of \$55.60 ha^{-1}.

Table 8. Partial Budgeting for Soybean without cover crop (SBNCC; an existing soybean production plan) *vs* Soybean with cover crop (SBCC; a proposed change of plan) for Walcott, AR.

Positive effects	Amount (\$ ha^{-1})	Negative Effects	Amount (\$ ha^{-1})
a. Increased revenue (From adopting SBCC)	1325.67	a. Decreased revenue (From not adopting SBNCC)	1417.1
b. Decreased costs (From not adopting SBNCC)		b. Increased costs (From adopting SBCC)	
Farm services	253.27	Herbicide application cost	81.54
		Cover crop seed cost	24.71
Total positive effects	1578.95	Total negative effects	1523.35
Profit (Total positive - negative)	**55.6**		

SBCC – Soybeans with cover crops. SBNCC – Soybeans without cover crops.

Table 9. Economic performance indicators for three different rice systems and two soybean rotation systems for Walcott, AR.

Year	Production practice	Total sales (\$ ha^{-1})	Total costs (\$ ha^{-1})	Total operating expenses (\$ ha^{-1})	Net income [a] (\$ ha^{-1})	Profit margin[b] (%)	Gross margin[c] (%)
					Economic Performance Indicator		
2020	MIRI	3042.25	1442.81	1477.38	1599.45	52.57	51.44
	FRCC	2388.44	1306.65	1289.33	1081.79	45.29	46.02
	FRNCC	2420.86	1417.84	1400.52	1064	43.95	42.15
					Economic Performance Indicator		
Year	Production practice	Total sales (\$ ha^{-1})	Total costs (\$ ha^{-1})	Total operating expenses (\$ ha^{-1})	Net income [a] (\$ ha^{-1})	Profit margin[b] (%)	Gross margin[c] (%)
2021	SBCC	536.5	305.33	225.42	231.17	43.1	58
	SBNCC	573.5	350.33	270.42	223.17	38.9	52.8

*[a] Net income = total sales (returns or revenue) – total costs. [b] Profit margin = (net income (or profit)/total sales) *100. [c] Gross margin = total sales - variable costs (operating costs)/total sales *100. FRCC – Furrow rice with cover crops. FRNCC – Furrow rice without cover crops. MIRI – Multiple inlet rice. SBCC – Soybeans*

To summarize, it is apparent from the analysis that changing to a furrow-irrigated rice system from MIRI may not be as profitable for producers unless it is considered as an initial investment and keeping the long-term soil health benefits and cost reductions in focus and taking small steps towards transformation.

Sensitivity Analysis: Table 9 summarizes the total costs and economic performance indicators of rice and soybean systems. For sensitivity analysis, we considered profit margin scenarios related to cost changes induced by alternative production practices. In the furrow-irrigated rice-soy rotation system with cover crops, the cost of rice/soybean and cover crop seed can also affect the decisions of adopting cover crops into a cropping system. Figure 3a and 3b shows the sensitivity in profit margin associated with the total seed cost (cash crop seed and cover crop seed) and only cover crop seed cost varying between -20% and +20% with 5% incremental change. The profit margin was more stable to fluctuations in total seed cost for MIRI followed by FRCC and then the least stable, FRNCC (Figure 3a). For the year 2021, the profit margin of SBCC was slightly more stable than SBNCC to fluctuations in total seed cost (Figure 3b). The sensitivity in profit margin associated with the cover crop seed cost showed that profit margins for FRCC and SBCC were not significantly affected by the changes in the cover crop seed cost (Figure 4a and 4b). This is likely due to the small share in the total production cost. Fig 5a and 5b demonstrates the sensitivity of profit margin with changes in herbicide cost ranging from -100% to +100% with ±10%, ±15%, and ±25% incremental change in rice and soybean. The profit margin of MIRI was more stable to fluctuations in herbicide cost followed by FRCC and FRNCC (Figure 5a) while in the soybean rotation phase SBCC was slightly more stable than SBNCC (Figure 5b). Figures 6a and 6b demonstrate the sensitivity in the profit margin due to changes in fertilizer cost ranging from -100% to +100% with ±10%, ±15%, and ±25% incremental changes. The profit margin was more stable for MIRI, followed by FRCC and FRNCC system (Figure 6a). Similarly, the profit margin was more stable for SBCC followed by SBNCC. The simulation reflected various scenarios that producers could consider when it comes to herbicides and fertilizer costs.

Figures 7a and 7b showcase the relationship between the total production cost and the combined expenses of cash crop and cover crop seeds. In comparison to Burdette, Walcott exhibited lower production costs for rice but higher costs for soybeans. However, changes in the total seed cost did not have a significant impact on the overall production costs. Nonetheless, FRNCC and MIRI systems consistently showed higher production costs compared to FRCC. This pattern persisted in the sensitivity analysis for soybean production costs, where SBNCC had higher costs compared to SBCC. Conversely, Figures 8a and 8b indicate that variations in cover crop seed costs had minimal influence on production costs, signifying that changes in seed costs did not significantly affect costs or profit margins. Additionally, Figures 9a and 9b illustrate the relationship between production costs and fluctuations in herbicide costs for rice and soybean crops. Among the evaluated systems (MIRI, FRCC, and FRNCC), there were no notable differences in production costs. Further analysis of the soybean phase revealed that a 100% increase or decrease in herbicide costs led to an 11% increase or decrease in total production costs (Figure 9b). Figures 10a and 10b indicate that at Walcott, there was no notable disparity in production costs when considering variations in fertilizer costs for rice, whereas in soybeans, SBNCC exhibited higher production costs compared to SBCC. A significant decrease of 100% in fertilizer costs resulted in a considerable reduction of 24% in production costs, while a 100% increase in fertilizer costs led to a 20% increase in production costs (Figure 10b). These findings shed light on the potential challenges that producers may face concerning production costs and input variables.

Discussion and Conclusions

The goal of this study was to determine the impact of winter cover crops on the profitability of furrow-irrigated rice-soybean rotation. Our research summarizes the enterprise budget, partial budget, and sensitivity analyses of rice-soybean rotation systems for the two research locations at Burdette and Walcott. Crop revenue, crop protection costs, seed costs, and farm operational costs were used to evaluate the profitability of cover crops in furrow-irrigated rice-soybean rotation systems. Partial budget analysis provided an assessment of the net economic returns of cover crops in the Arkansas furrow rice-soybean rotation system. For Burdette, considering the change from MIRI to FRCC system and FRNCC to FRCC system, was not profitable whereas the change from MIRI to FRNCC was profitable. In soybean rotation, considering the change from SBNCC to SBCC was profitable. At Walcott, the partial budget analysis considering the change from MIRI to FRCC or FRNCC was not profitable while the change from FRNCC to FRCC and SBNCC to SBCC was profitable. The difference in cash crop yields and production costs resulted in the variability of net effects in both rice and soybean crops. The cost-benefit ratios for the same cash crop varied between the two locations, the benefit-cost ratio was much lower for FRCC (0.16) at Burdette in 2019 compared to the FRCC (0.84) at Walcott in 2020. This indicates that adopting furrow-irrigated rice with cover crops can have mixed effects on different farm enterprises at different locations. At Walcott, the benefit-cost ratios of SBCC (1.03) and SBNCC (0.83) were lower compared to Burdette SBCC (3.69) and SBNCC (3.21) but for both locations, SBCC showed to be more profitable compared to SBNCC indicating that soybeans can be a good entry crop for producers to begin using cover crops.

The differences in profitability of using winter cover crops between the two locations or two farm enterprises were likely due to the different management challenges. Given the relatively close proximity of the two locations, ~ 93 km apart, there is minimal variation in climate conditions. Consequently, factors such as temperature, rainfall patterns, humidity, and sunlight availability did not exert a significant influence on the profitability of cover crops in the two locations. Differences in soil type indeed have a significant impact on the management practices of each location. In case of Walcott, the cost of fertilizer for rice was 40% higher compared to Burdette. This difference can be attributed to the specific fertilizer requirements of silt loam soils, which require a higher application of fertilizers compared to heavy clay soils with a high cation exchange capacity (CEC). The presence of charged sites in the soil directly affects the availability of nutrients, and soils with different textures but the same level of acidity require distinct recommendations for fertilizer application (Finch et al., 2014).

At Burdette, farm services, machinery costs, and farm overhead costs for rice and soybeans were higher compared to Walcott. This is primarily due to the specific soil characteristics that require intensive ploughing and subsequent cultivations, which demand more tractor power compared to other soil types. All cultivations must be very carefully timed (usually restricted to a shorter period than on other soil types) so that the soil structure is not damaged (Finch et al., 2014). Increased machinery costs in Burdette can be attributed to the higher power requirements and the need for specialized equipment to carry out the necessary cultivations and maintain soil quality. Additionally, the farm overhead costs, which include various expenses apart from machinery, are also higher in Burdette due to the additional care and attention needed for cultivating crops in these specific soil conditions. The total herbicide cost differed between the two locations due to variations in weed pressure and the cost of herbicides is influenced by the amount of weed infestation in each location. Seed cost also varied between the two locations as different enterprise prefer different seeding rates. When the seeding rate is increased, more seeds are required to cover the same area, resulting in higher seed costs. However, it is essential to maintain a balance between seed cost and attaining an adequate plant stand to ensure optimal crop performance and profitability. In addition to the differences in management, the Burdette study site experienced a challenge with poor soil contact with rice seed (FRCC) being planted into cover crop biomass. This delayed the rice crop establishment early during the season which resulted in reduced yields, which in turn led to reduced net returns. Apart from cultivation cost, yield played a significant role in the profitability of utilizing winter cover crops in these systems. The soybean portion of the rotation at both locations appeared to withstand the financial requirements of winter cover cropping and proved to be profitable. These estimates of the costs and returns for each cropping system can assist growers in making decisions regarding the use of cover crops and making specific management changes to maximize profits in rice-soybean rotations. The sensitivity analyses further support the decision-making process while accounting for the potential risks in input costs.

This research contributes towards evaluating the economic costs and profitability of adopting cover crops in a rice-soybean rotation system. Conducting both enterprise and partial budget analyses for winter cover crops grown in a rice production system provides valuable insights for decision-making, but they have their respective strengths and limitations. An enterprise budget analysis for cover crops in rice allows for a comprehensive assessment of costs, profitability, and financial planning. It provides a holistic view of the financial implications, considering various inputs and outputs, enabling farmers to make informed decisions based on profitability. However, it may overlook contextual factors like environmental benefits and long-term sustainability (Fang, 2019). On the other hand, a partial budget analysis focuses on evaluating the financial impact of specific changes, such as integrating cover crops, offering flexibility and adaptability. It helps farmers assess incremental costs and benefits, aiding in decision-making and resource allocation. Nevertheless, the narrow focus on financial aspects may exclude other essential factors like soil health improvements (Dalsted, 2002). Both analyses require accurate data, but partial budget analysis may be more feasible for farmers as it requires less time and effort. Nonetheless, uncertainties, sensitivity to assumptions, and data availability can pose challenges for both analyses. Therefore, a combination of enterprise and partial budget analyses can provide a more comprehensive understanding of the financial viability and benefits of cover crops in rice farming, while considering the broader context and limitations of each approach. A sensitivity analysis for cover crops in a rice-soybean rotation helps identify key factors influencing the system's performance, optimizing cover crop management practices for maximum benefits. Additionally, sensitivity analysis enables risk assessment by evaluating the system's vulnerability and resilience to various scenarios. However, it has limitations. The complexity and interactions within the system may be oversimplified, and data availability can be limited, impacting the accuracy of the analysis (Saltelli et al., 2007). Despite these limitations, sensitivity analysis, when combined with other research approaches and local expertise, can provide valuable insights for decision-making in cover crop management.

The results of this research are critical for producers as winter cover crop adoption in furrow-irrigated rice systems has challenges. Winter cover crops can be economically viable under certain circumstances, and depends on factors like management, productivity of cash crop and some uncontrollable factors like soil type and weather (DeVincentis et al., 2020). Cover crops can be a potential long-term investment and farmers should consider the implications of using cover crops on their farm to ensure profitability (DeVincentis et al., 2020). Additionally, policy incentives offered through Environmental Quality Incentives Program (EQIP), or the Conservation Stewardship Program (CSP) may help producers by subsidizing payments for adopting furrow-irrigated rice with cover crops and generate a low-risk situation for farms. The economic analysis in this study significantly contributes to the evaluation of conservation practices like cover crops and highlights the importance of these economic evaluations to producers in adopting cover crops.

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APPENDIX

Enterprise Budget For Furrow-irrigated rice with cover crops - 2019.							
2019 Rice Budget,							
Rice (With cover crops)							
Acres - 74.80 acres							
CROP VALUE	**Grower %**	**Unit**		**Yield**	**Price($)/Unit**	**Revenue**	**Revenue/ Acre**
Crop Value	100%	Bu.		153.77	5.4	62110.78	830.36
OPERATING EXPENSES							
CROP PROTECTION							
Product	**Grower%**	**Unit**	**Rate /Acre**	**Qunatity (Product applied/74.80acres)**	**Price($)/Unit (of Product)**	**Total Cost**	**Price($)/ Acre**
Glyphosate 41% Plus	100%	Gallons	53.63 fl oz	32.92	10.29	338.90	4.53
Malathion 5	100%	Gallons	0.00 gal	0.01	42.00	0.42	0.01
Drop-Point	100%	Gallons	0.19 fl oz	0.11	39.55	4.35	0.06
Rapport BroadSpec	100%	Lbs	0.02 dry oz.	0.08	98.38	7.87	0.11
De-Ester LV6	100%	Gallons	0.01 gal	0.80	18.14	14.51	0.19
Promote	100%	Dry oz.	2.390 dry oz.	119.18	16.22	1933.01	25.84
Facet L Herbicide	100%	Gallons	0.01 gal	0.50	84.84	42.42	0.57
Bolero 8 EC	100%	Gallons	0.02 gal	1.30	52.34	68.04	0.91
Sharpen Powered by Kixor Herbicide	100%	Gallons	0.016 gal	1.38	605.86	836.09	11.18
Loyant	100%	Gallons	19.74 fl oz	2.00	256.24	512.47	6.85
Prize	100%	Gallons	0.00 gal	0.29	161.10	46.72	0.62
Drexel Pin-Dee 3.3 EC	100%	Gallons	0.42 fl oz	0.24	26.79	6.43	0.09
Clomazone 3ME	100%	Gallons	16.44 fl oz	10.14	70.62	716.07	9.57
AMS	100%	Gallons	0.00 gal	0.21	10.10	2.12	0.03
OutRight	100%	Gallons	0.41 fl oz	0.24	60.29	14.47	0.19
Msma 6 Plus	100%	Gallons	0.05 fl oz	0.03	36.33	1.09	0.01
Hyvar X-L	100%	Gallons	0.00 gal	0.02	93.00	1.86	0.02
Drift Control	100%	Gallons	17.17 fl oz	10.03	1.00	10.03	0.13
Gundown Elite	100%	Gallons	0.33 fl oz	0.19	20.37	3.87	0.05
Water	100%	Gallons	47.36 gal	1274.70	0.00	0.00	0.00
Crop Oil Concentrate	100%	Gallons	36.27 fl oz	13.70	10.07	137.99	1.84
Paraquat Concentrate	100%	Gallons	56.76 fl oz	3.32	20.48	67.99	0.91
NipSit INSIDE Insecticide - Rice - 45Lb.Bag	100%	Lbs	23.00 lb	38.23	0.00	0.00	0.00
Vibrance Rice - 45lb bag	100%	Lbs	23.00 lb	38.23	0.00	0.00	0.00
Extreme COC	100%	Gallons	64.00 fl oz	37.39	14.46	540.80	7.23
Lambda-Cy 1EC	100%	Gallons	7.70 fl oz	4.50	49.42	222.40	2.97
RebelEX	100%	Gallons	32.00 fl oz	18.70	196.94	3682.82	49.24
ContaiN	100%	Gallons	13.44 fl oz	7.85	0.00	0.00	0.00
Metalica	100%	Gallons	14.70fl.oz	0.6	25.18	15.11	0.20
Superior MSO	100%	Gallons	13.57 fl oz	0.30	17.50	5.25	0.07
FERTILIZER							
Urea 46-0-0	100%	Tons	492.17 lb	18.40	305.27	5,617.03	75.09
SEED							
Barley Cover Crop	100%	Lbs	20.18 lb	1554.5	0.64	993.25	13.28
XP753	100%	Lbs	24.00 lb	1803.15	6.91	12,458.57	166.56
SERVICE							
Diesel Fuel - Gallon	100%	Gallons	8.61 gal	573.93	2.16	1,242.55	16.61
Seeding - Air Cart	100%	Acre	1.00 ac.	152.17	18.83	2,865.34	38.31
Row Rice Scouting	100%	Acre	1.00 ac.	74.8	10.00	747.96	10.00
Delivery Charge	100%	Acre	1.00 ac.	0		9.52	0.13
Ditching	100%	Acre	1.00 ac.	74.8	0.71	53.10	0.71
Harrowing - Kelly Diamond	100%	Acre	1.00 ac.	81	9.21	746.01	9.97
Bedder - Roller	100%	Acre	1.00 ac.	74.8	9.72	727.01	9.72
Row Cultivating	100%	Acre	1.00 ac.	70.37	6.99	491.89	6.58
Ground-rig Spraying	100%	Acre	1.00 ac.	92.64	6.28	581.75	7.78
Hooded Sprayer	100%	Acre	1.00 ac.	7.48	6.52	48.77	0.65
Spraying - Air 5 GPA	100%	Acre	3.00 ac.	224.127	6.33	1,418.75	18.97
Polypipe - Service	100%	Acre	1.00 ac.	74.8	9.07	678.40	9.07
Poly Pipe	100%	Roll	0.03 roll	1.97	324.03	638.33	8.53
Spreading - Air 160 Lbs. (Service)	100%	Acre	1.00 ac.	149.6	10.78	1,613.20	21.57
Spraying - Air 7GPA	100%	Acre	1.00 ac.	74.81	6.25	467.56	6.25
Spreading - Air 100 Lbs.	100%	Acre	1.00 ac.	74.8	6.74	504.26	6.74
Spreading - Air 70 Lbs.	100%	Acre	1.00 ac.	37	7.00	259.00	3.46
Irrigation - Natural Gas	100%	Acre	1.00 ac.	74.8	41.25	3,085.32	41.25
Grain Cart - S790 Stripper Head	100%	Acre	1.00 ac.	74.8	15.34	1,147.36	15.34
Harvest - S790 Stripper Head	100%	Acre	1.00 ac.	74.8	58.29	4,359.83	58.29
Crop insurance	100%	Acres				919.29	12.29
Interest on op expenses (For 6 months)	100%	Rate%		25,453.58	0.06	1,399.95	18.72
Total Operating Expenses						**49,987.86**	**668.29**
Gross margins (Income over operating expenses)						12122.92	162.07
FIXED EXPENSES							
Landlord's share (25%)	100%	Acres				-1170.62	-15.65
Landlord's storage charge	100%	Acres				-924.528	-12.36
Machinery (UofA budget average)	100%	Acres				6068.524	81.13
Farm overhead							
Technology & Data Consulting	100%	Acre	1.00 ac.	74.8	4.95	370.24	4.95
Overhead Labor	100%	Acre	33.67 ac.	2,518.45	1.00	2,518.45	33.67
Total fixed expenses						**3973.376**	**53.12**
TOTAL COSTS OF PRODUCTION						**53,961.24**	**721.41**
NET RETURNS/PROFIT						**8149.54**	**108.95**

Figure S1. Enterprise Budget for Furrow-irrigated rice with cover crops - 2019.

Enterprise Budget for Soybeans with Cover Crops - 2020.

2020 Soybean Budget,
Soybean-(With Cover crops)
Acres - 74.80 acres

CROP VALUE	**Grower %**	**Unit**		**Yield**	**Price($)/Unit**	**Revenue**	**Revenue/ Acre**
Crop Value	100%	Bu.		67.14	9.25	46454.17	621.05
OPERATING EXPENSES							
CROP PROTECTION							
Product	**Grower%**	**Unit**	**Rate /Acre**	**Qunatity (Product applied)**	**Price($)/Unit (of Product)**	**Total Cost**	**Price($)/ Acre**
RedEagle Flumioxazin 51% WGD (77.23acres)	100%	Lbs.	0.12 lbs.	9.27	21.99	203.89	2.64
Agsaver Glyphosate 41% Plus (77.23acres)	100%	Gallons	40.6 floz	24.50	12.14	297.34	3.85
Agsaver Glyphosate 41% Plus (76.63 acres)	100%	Gallons	52.05 floz	31.16	12.15	378.55	4.94
Metalica (76.63 acres)	100%	Gallons	16.02 floz	9.59	23.97	229.89	3.00
SEED							
Barley Cover Crop NVS (78.85 acres)	100%	Lbs	9.99 lbs.	787.32	0.34	267.30	3.39
Rye Cover Crop NVS (78.85 acres)	100%	Lbs	9.99 lbs.	787.32	0.34	267.30	3.39
P46A86X (17.05 acres)	100%	Lbs	155000 seeds	18.88 bag		1,033.57	60.62
P48A32X (56.98 acres)	100%	Lbs	155000 seeds	63.09 bag		3,073.73	54.80
SERVICE							
Airseeder/seeding (78.85 acres)	100%	Acres	1.00 ac.	78.85	18.83	1,484.75	18.83
Diesel-red (78.85 acres)	100%	Gallons	0.36 gal	28.39	2.17	61.50	0.78
Planting (17.05 acres)	100%	Acre	1.00 ac.	17.05	6.66	113.55	6.66
Diesel-red (17.05 acres)	100%	Gallons	0.24 gal	4.09	2.17	8.87	0.52
Boomspray application (77.23acres)	100%	Acres	1.00 ac.	77.23	6.28	485.00	6.28
Diesel-red (77.23acres)	100%	Gallons	0.06 gal	4.63	2.17	10.04	0.13
Diesel-red (56.98 acres)	100%	Gallons	0.24 gal	13.68	2.17	29.63	0.52
Planting (56.98 acres)	100%	Acre	1.00 ac.	56.98	6.66	379.49	6.66
Boomspray application (76.63 acres)	100%	Acre	1.00 ac.	76.63	6.28	481.24	6.28
Diesel-red (76.63 acres)	100%	Gallons	0.06 gal	4.6	2.16	9.96	0.13
Inter row cultivation (72.66 acres)	100%	Acre	1.00 ac.	72.66	4.25	308.81	4.25
Diesel-red (72.66 acres)	100%	Gallons	0.26 gal	18.89	2.15	40.69	0.56
Harvest - soybeans (74.75 acres)	100%	Acre	1.00 ac.	74.75	40.74	3,045.28	40.74
Diesel-red (74.75 acres)	100%	Gallons	1.19 gal	88.95	2.16	192.21	2.58
Crop insurance	100%	Acres				710.60	9.50
Interest on op expenses (For 6 months)	100%	Rate%		6,556.58	0.06	360.61	4.82
Total Operating Expenses						**12,402.57**	**165.81**
Gross margins (Income over operating expenses)						34051.60	455.24
FIXED EXPENSES							
Landlord's share (70%)	100%	Acres				-16984.836	-227.07
Landlord's storage charge	100%	Acres				-1226.72	-16.40
Machinery (UofA budget average)	100%	Acres				6442.524	86.13
Farm overhead	100%	Acre	1.00 ac.	74.8	4.31	322.39	4.31
Total fixed expenses						**-11769.032**	**-157.34**
TOTAL COSTS OF PRODUCTION						**633.54**	**8.47**
NET RETURNS/PROFIT						**45820.63**	**612.58**

Figure S2. Enterprise Budget for Soybeans with Cover Crops - 2020.

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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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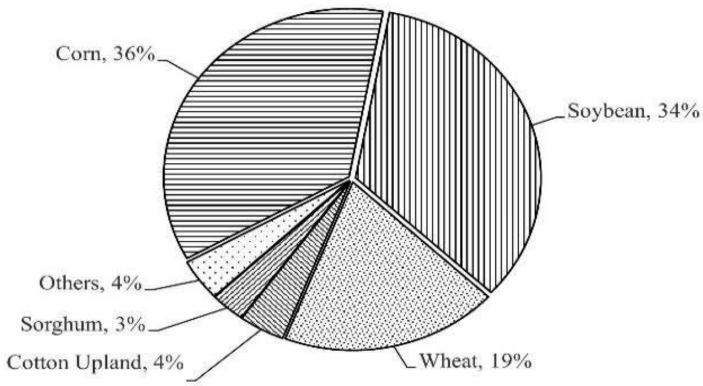

Figure 1. Planted acres in the United States, 2011.

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 et 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 September 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.

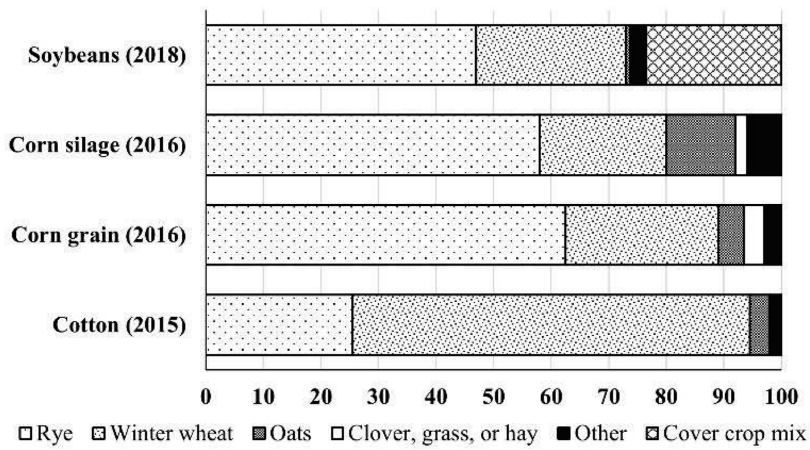

Figure 2. Cover crops used in the United States in cotton, corn grain, corn silage, and soybean from 2015 to 2018.

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). 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). 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.

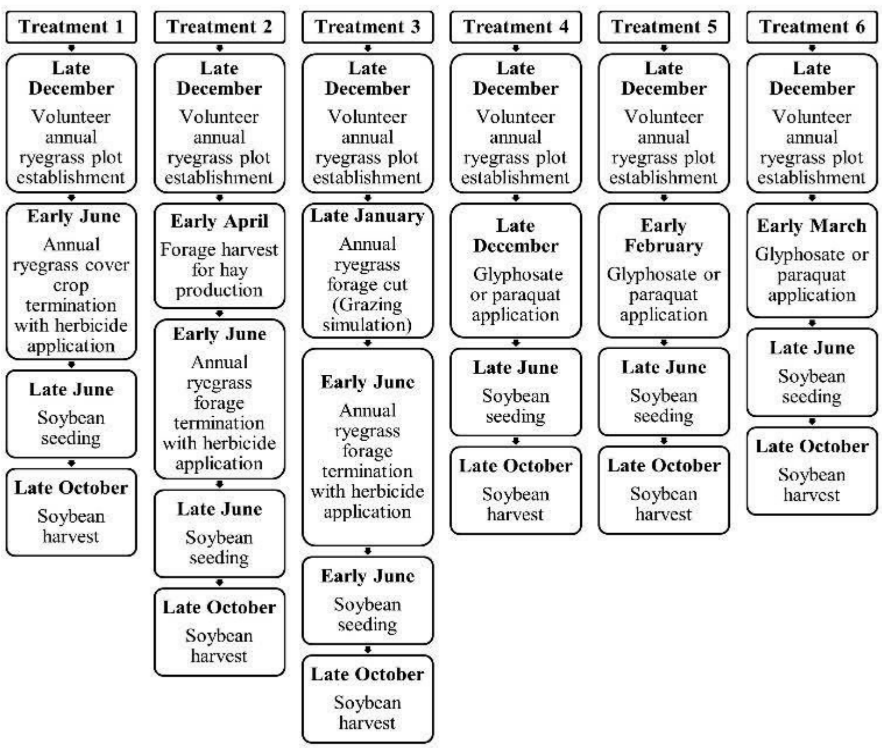

Figure 3. Timeline of ryegrass management practices evaluated.

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 early in June 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}. At least two weeks later, in late June, soybeans with a glyphosate and dicamba tolerant variety (Asgrow AG49X) were seeded. Soybean plots received a post emergent application of glyphosate, s-metolachlor, and dicamba to control weeds until harvest. Soybean seed was harvested in October 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	Units
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 is 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	Units
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 LSMEAN --- kg ha^{-1} ---			2022 LSMEAN --- kg ha^{-1} ---		Overall 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 establishing soybean (Table 5), and \$229.82 ha^{-1} when using glyphosate (Table 6). Sensitivity analysis for ryegrass demonstrated that if hay prices drop to \$0.10 kg^{-1}, ryegrass production will not be profitable (Tables 5 and 6). 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 (Tables 5 and 6). 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 1,006.70 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.

Last, ryegrass cover cropping (treatment 1) was able to control 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 general, using just one early herbicide application before soybean establishment allows resistant ryegrass and other existent weeds to grow and spread along the plots, which negatively affects soybean yield.

Table 10. Sensitivity Analysis for Volunteer Annual Ryegrass Hay Production Terminated with Glyphosate Systemic 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	*($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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Modeling Crop Rotations Under Risk in Order to Maximize Grower Returns

Adriana Dimas and Michael Deliberto

Crop enterprise(s) selection is one of the most critical decisions growers face. Growers have preferred outcomes but must account for its statistical probability in achieving those preferred outcomes given their resource endowment subject to prevailing market conditions and other variables while seeking to minimize risk in such decisions. Traditionally, risk can come from either variability in yields, market prices, and production input costs requisite to the cultivation of each crop enterprise. To analyze risk and its impact on crop enterprise selection, four representative farms were established within Louisiana and Arkansas to evaluate net return variability among alternative crop enterprises and rice cultivar selection using regionally specific stochastic efficiency criterion. The aim of this study is to evaluate which crop enterprise choice(s), within both continuous and rotational management strategies, best maximizes grower profitability over alternative rice cultivar and crop enterprise selections subject to a prescribed range of risk aversion levels.

Key words: Enterprise Selection, Net Returns, Representative Farm, Risk

Arkansas is the top rice-producing state in the U.S., generating more than $1.332 billion in cash receipts (University of Arkansas, 2023). In total, rice accounted for approximately 13% of total receipts ($10.4 billion). Soybeans generated cash receipts of $1.653 billion (16% of total cash receipts), corn $652 million (6%), and cotton generated $537 million (5%) in 2021. These crop enterprises can be produced in rotation and are common amongst producers in the Mississippi River Delta Region of the state, with the collective share totaling 40% of total cash receipts for Arkansas. Louisiana's rice producers generated a gross farm value of $432.6 million in 2022. This represents 6% of the state's $7.74 billion in total farm gate earnings (Louisiana State University AgCenter, 2022). Soybeans generated $843 million in gross farm earnings (11% of total farm gate value), corn $536 million (7%), crawfish $306 million (4%), and cotton $209 million (3%). Unlike other states, corn is not grown in southern Louisiana where a majority of the state's rice crop is produced. Crawfish is an aquaculture crop unique to Louisiana that figures prominently in its ability to be produced in rotation with rice. Crawfish - and to a lesser extent soybeans - are common cropping options to be produced in rotation with rice for southern Louisiana producers given the complementary nature shared between crawfish pond design and construction and rice paddy field levees. Corn, cotton, and

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soybean rotations are common to the central and northern regions of the state, especially with the advent of poly-pipe irrigation systems. In total, these crops account for 31% of total gross farm value for Louisiana's agriculture sector.

From an economic perspective, enterprise budgeting has traditionally been an important tool decision-makers have utilized when deciding which crop enterprise(s) is both (a) the most risk-efficient and (b) offers the optimal opportunity of generating the maximum level of net returns over a prescribed range of risk aversion preferences. The notion of risk aversion is a fundamental feature of the problem of choice under uncertainty. This notion is made precise when the consequences that matter to the decision maker are monetary outcomes, such that the utility function of an individual is defined over wealth, given a utility function, $U(w)$, where w represents wealth. Intuitively, a decision maker (e.g., an agricultural producer) is said to be risk averse if, for every lottery $F(w)$, the individual will always prefer (at least weakly) the certain amount, expressed as the expected $E[w]$ to the lottery $F(w)$ itself (Arrow 1965; Pratt 1964).

Crop enterprise selection is a key component of this process when determining the operational maximization of net returns, especially in geographical areas that boast the ability of producing diverse crops (e.g., Louisiana and Arkansas). Each crop enterprise possesses its own unique risk profile that stems from such factors as market conditions, weather variability, and those commodity production costs that directly affect net returns per acre. Volatility in either one or multiple factors can result in the election of one alternative crop enterprise, or combination, over another crop enterprise (or combination thereof).

Farms located in the Mississippi River Delta Region of Arkansas and Louisiana are suited to produce corn, soybeans, and cotton in rotation given the row configuration and the ability to irrigate these crops via either poly pipe or center pivot systems from nearby water sources or available aquifers. However, rice is a crop which differs between the two states. Rice can be produced in rotation with grain crops in Arkansas. In Louisiana, 70% of rice is produced in the southern part of the state in rotation with crawfish and soybeans. The remaining portion of the state's rice is grown in northern Louisiana with farm management plans consisting of corn, soybeans, and, to a limited extent, cotton. Specific to the Mid-South Region of the United States, there has been a decline in the profitability of cotton production relative to corn and soybeans. As the price differential has increased, there has been a switch away from cotton to corn and soybean plantings (Poulsen, 2018). This is evident that market factors dictate enterprise selection.

Furthermore, simulation modeling can estimate net returns for each crop enterprise by constructing representative farms which simulate production conditions for a particular geographical region over a given set of minimum and maximum bounds. Farm-level simulation and risk analysis afford decision-makers a better feel for the potential impacts alternative cropping strategies could offer. The inherent uncertainties surrounding the intensely competitive environment of crop enterprise selection warrants use of such techniques. Producers are constantly trying to maximize economic returns. A common practice for many producers in some parts of the U.S. is to rotate crops. Crop rotations provide greater options for increased income and decreased production risk by increasing agronomic yields via potential yield increases, lowering the incidences of pest and/or weed pressure, thus positively augmenting economic returns (Martin, Cooke, and Parvin, 2002).

The general objective of this study is to evaluate the potential impacts competing enterprise crops such as corn, cotton, rice, soybeans, and crawfish have on producers' net returns over risk. This research is aimed at evaluating which crop enterprise (or combination), within both continuous and rotational management strategies, optimally maximizes profitability over alternative crop selections for a prescribed range of risk aversion levels for four representative farms.

Methods

Representative Farm Approach

Representative farms are virtual farms that model both production and cultivation practices that are crop and regional specific. By utilizing projected prices, input costs, and policy parameters while simultaneously incorporating historical risk components, the representative farm approach possesses the ability to assess how much risk each modeled farm may encounter under the assumptions of projected prices, yields, input costs, etc. The representative farm approach treats a farm business unit as a unique entity characterized by local features and resources and assumes adaptations are made by farm management. Local conditions are internalized in the creation and simulation of each farm. To simulate each possible crop enterprise's profitability potential and risk profile, representative farms were constructed for Acadia and East Carroll parishes in Louisiana and for Arkansas and Mississippi counties in Arkansas, specific to localized crop price and yield distributions, utilizing USDA National Agriculture Statistical Service (NASS) data from 2013 to 2022 for rice, soybeans, corn, cotton, and crawfish (for Louisiana only). The purpose of representative farm analysis is to construct an economic model that is representative of a particular row cropping farming operation. Relying on panel data sourced from local producers, a baseline scenario is constructed in order to gauge the viability of the area's row crop agricultural community under current production systems, product prices, and farm program policy provisions as a means of best modeling that operation's economic performance under those unique set of assumptions (Hogan, Watkins, and Wailes, 2006). The model incorporates actual prices and production risks that optimally models the economic performance of that operation under a unique risk profile for those actual farms for a distinct geographical region.

The four representative farms reflect common crop enterprises in each region to best determine which crop enterprise yields the greatest profitability while simultaneously minimizing risk over a prescribed range of risk aversion levels. Selected farm input unit prices for key inputs (e.g., nitrogen, phosphate, potash, and diesel fuel) used in the production of corn, cotton, rice, soybeans, and crawfish for the observed period were obtained from the state extension services of Arkansas and Louisiana. The energy-related inputs of fertilizer and fuel comprise a majority share of the variable production costs per acre for corn, cotton, rice, and soybean production systems in both Arkansas and Louisiana. For example, in 2022, fertilizer for corn commanded nearly 49% of the total direct production costs per acre in Arkansas. Together, fertilizer and fuel utilized in rice production in Arkansas accounts for 45% of total direct production costs (University of Arkansas, 2023). Also, for the 2022 crop year, fertilizer utilized in Louisiana corn production accounts for 34% of the total direct cost of production. For Louisiana rice producers, fertilizer share was estimated to represent 27% of the total direct cost of production per acre while fuel accounted for another 22% (Louisiana State University AgCenter, 2023).

To simulate each crop enterprise's profitability and risk level, representative farms were constructed specific to localized crop price and yield distributions. A simulation model was used to generate a total of 1,000 iterations per variable to approximate the distribution of the grower's share of net returns above variable costs using Simetar® subject to localized farm data (i.e., historical yields, market prices, and the farm energy-related input cost estimates for each crop enterprise).

Simulation Analysis

Simulation in risk analysis aims to estimate the distributions of economic returns of alternative strategies for decision makers to assist them in the decision-making process (Richardson, 2010). Stochastic simulation allows for the parameter's simulated distribution value to be subject to unpredicted occurrences, which are correlated to risk, and represent the range of randomly distributed outcomes indicative of the presence of risk which must be accounted for in the decision-making process (Flanders, 2008). To analyze net returns in relation to crop enterprise selection, stochastic modeling was used to capture the fluidity of market prices, yield variability, and input price volatility that impact grower profitability.

Table 1. Historic input prices for selected farm inputs for Arkansas and Louisiana representative farms, 2013-2022.

	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Arkansas											
Nitrogen Fertilizer	$/lb	$0.61	$0.45	$0.43	$0.39	$0.33	$0.35	$0.46	$0.50	$0.35	$1.08
Phosphate Fertilizer	$/lb	$0.64	$0.52	$0.50	$0.50	$0.41	$0.41	$0.24	$0.47	$0.39	$1.02
Potash Fertilizer	$/lb	$0.48	$0.39	$0.37	$0.33	$0.24	$0.26	$0.19	$0.45	$0.25	$0.75
Diesel Fuel	$/gal	$3.60	$3.17	$2.48	$1.90	$1.75	$2.20	$2.50	$2.50	$1.60	$3.89
Louisiana											
Nitrogen Fertilizer	$/lb	$0.56	$0.50	$0.50	$0.43	$0.32	$0.34	$0.43	$0.41	$0.38	$0.76
Phosphate Fertilizer	$/lb	$0.65	$0.50	$0.61	$0.54	$0.49	$0.40	$0.55	$0.38	$0.39	$0.65
Potash Fertilizer	$/lb	$0.47	$0.37	$0.34	$0.35	$0.26	$0.26	$0.32	$0.27	$0.28	$0.59
Diesel Fuel	$/gal	$3.31	$3.30	$2.75	$2.00	$1.85	$2.80	$2.50	$2.44	$1.73	$2.84

Table 2. Historic commodity prices for selected crops in Arkansas and Louisiana, 2013-2022.

	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Arkansas											
Corn	$/bu	$5.12	$4.13	$4.11	$3.69	$3.64	$3.80	$3.86	$4.49	$5.95	$6.70
Cotton	$/lb	$0.79	$0.64	$0.66	$0.69	$0.71	$0.71	$0.61	$0.69	$0.80	$0.83
Rice	$/cwt	$15.20	$12.00	$10.90	$9.39	$11.10	$10.70	$11.90	$12.50	$13.80	$16.70
Soybeans	$/bu	$13.10	$10.60	$9.46	$9.83	$9.77	$8.81	$8.87	$10.50	$12.90	$14.20
Louisiana											
Corn	$/bu	$5.10	$4.15	$4.00	$3.70	$3.72	$3.86	$3.86	$3.74	$5.29	$6.70
Cotton	$/lb	$0.78	$0.63	$0.68	$0.70	$0.72	$0.76	$0.64	$0.67	$0.88	$0.83
Rice	$/cwt	$15.50	$12.90	$11.40	$10.20	$11.70	$11.20	$11.80	$12.60	$14.10	$16.70
Soybeans	$/bu	$13.40	$10.90	$9.74	$9.93	$9.67	$8.95	$8.70	$10.00	$12.40	$14.20
Crawfish	$/lb	$1.35	$1.35	$1.42	$1.45	$1.35	$1.38	$1.43	$1.34	$1.29	$1.40

Stochastic Efficiency with Respect to a Function

To make comparisons of outcomes, thus creating rankings for those optimal decisions as opposed to those that are less preferable, individualized risk preferences for decision makers need to be ascertained. A utility function, often expressed as a function of wealth, net returns, or profitability, can help determine the shape of a decision maker's attitude towards risk. Upon identifying a specific utility function that most accurately models an individual decision maker's risk profile, stochastic dominance or efficiency analysis can then be utilized to rank alternative options. Stochastic Efficiency with Respect to a Function (SERF) is a variant of Stochastic Dominance with Respect to a Function (SDRF) that orders a set of risky alternatives in terms of Certainty Equivalents (CE) calculated for specified ranges of risk attitudes (Hardaker et al., 2004).

The CE of a risky prospect is the sure sum with the same utility as the expected utility of the prospect. In other words, for a given utility function, it is the point mass at which the decision maker is indifferent between the value and the risky outcome (Hardaker et al., 2004).

SERF gives ordinal and cardinal rankings by using CEs to communicate the most preferred decision (highest CE at specified levels of risk aversion) to the least preferred (lowest CE at specified levels of risk aversion) over a range of absolute risk aversion coefficients (ARACs) so that given a set of risky alternatives, those alternatives can be ranked simultaneously. An appropriate range of ARACs must be specified for calculating CEs with the negative exponential utility function. ARACs represent a decision maker's degree of risk aversion. Decision makers are risk averse if ARAC > 0, risk neutral if ARAC = 0, and risk preferring if ARAC < 0. Cardinal rankings are the utility measurement when satisfaction gained by the grower from the choice of a cropping enterprise which can be measured numerically. Ordinal rankings are utility measurements that are related to the grower's choice of a cropping enterprise that cannot be measured numerically. Risk premiums may also be calculated using SERF, these are a cardinal measure of a decision maker's conviction for preferences among risky alternatives and may be calculated as the difference in CEs between two risky alternatives for a given level of risk aversion (Hardaker et al., 2004). This method is proven to compare multiple decision alternatives efficiently and effectively by using pairwise comparison of the decisions in terms of CE, defined as wealth, over the specified level of risk aversion.

An analysis of expected utility can deliver decision recommendations for different levels of risk aversion on the part of a decision-maker by transforming probabilistic estimates of possible outcomes into an expected utility value using a utility function (Hardaker et al., 2015). The concavity or convexity of the utility function indicates individual risk preference profiles, ranging from 'risk-taking, over 'risk-neutral', to 'risk-averse'. Analysis of expected utility can therefore deliver detailed decision support that accounts for the decision-maker's risk preferences (Ruett et al., 2022).

A utility function commonly associated with SERF is the negative exponential utility function. Hardaker et al. (2004) recommends this functional form because it is a constant absolute risk aversion function which can reasonably approximate not only the actual but also the unknown utility function. The negative exponential utility function also conforms to the hypothesis that decision-makers prefer the least risk given the same expected return among given crop alternatives (Watkins et al., 2018). SERF gives ordinal and cardinal rankings by using CEs to distinguish between the most preferred decision (highest CEs at specified levels of risk aversion) and the least preferred (lowest CE at specified levels of risk aversion). An appropriate range of Absolute Risk Aversion Coefficients (ARACs) must be specified for calculating CEs with the negative exponential utility function. ARACs represent a decision-maker's risk aversion profile.

Net Returns

Specific cost estimates are used to represent the (parish) county-level cost of production estimates in replicating regional input cost variability. Key production input cost data for rice, soybeans, corn, cotton, and crawfish were derived from enterprise budgets published by both the Louisiana State University Agricultural Center and the University of Arkansas, Division of Agriculture. The distributions of grower share of net returns above variable costs were calculated using simulated yield and price variables based on actual historical yields, market prices, and estimates for key farm input costs for each crop enterprise from 2013-2022. In this study, key production inputs of fertilizer and diesel fuel were the two variable cost categories chosen since they comprise a significant portion of each crop enterprise's total variable costs. The grower's share of net returns above variable costs will act as a proxy for CE (dollars per acre). A simulation analysis of the net returns for each crop enterprise per state will be imposed against each other for each regional representative farm. Representative farms will be modeled to reflect those crop enterprises most common in each region to determine which crop enterprise selection yields the greatest profitability whilst simultaneously minimizing risk.

The estimation of the grower's share of net returns per acre ($GRWNR_{itn}$) for crop i, year t, and iteration n, assumes that corn, cotton, crawfish, rice, and soybeans will be produced in the representative farm's region to reflect the historical area of production. To estimate the net returns of each representative farm's crop mix, Equation 1 expresses the grower's share net returns per acre less the estimated direct production costs of the required farm inputs.

(1) $$GRWNR_{itn} = \sum_{i=1}^{2} \sum_{t=1}^{10} \sum_{n=1}^{1000} \{ [RNT * (Y_{itn} * P_{itn}) + -SVC_{itn} - NSVC_{itn}\}$$

The grower's share of net returns ($GRWNR_{itn}$) was simulated in Simetar® with state-level commodity prices (PR_{itn}) and county yields (Y_{itn}) as key inputs, where SVC_{itn} represents stochastic variable costs for crop *i*, year *t,* and iteration *n*, and $NSVC_{itn}$ represents non-stochastic variable costs for crop *i*, year *t,* and iteration *n.* Grower's share of net returns above variable costs will be expressed as a percent of a rotational acre. In equation (1), the stochastic variable cost categories were identified as unit prices for nitrogen, phosphate, and potash fertilizer, and diesel fuel. The non-stochastic variable costs were those costs associated with chemicals, repairs, interest on operating capital, and other field expense categories originating from each crop's enterprise budget.

SERF risk analysis was then used to analyze which crop enterprise alternative is the most risk-efficient in maximizing profit across a range of risk aversion preferences. The CEs are estimated assuming different risk aversion coefficients using 1,000 simulated net returns for each system (Hardaker et al., 2004). The interpretation of CE values in terms of wealth over risk will rank, both ordinally and cardinally, those crop enterprise selections that maximize highest net returns (highest CE values) for each specific level of risk.

Results

The economic analysis of alternative crop enterprise selection will determine the most profitable and risk efficient crop enterprise selection for the farm, which will be calculated using SERF to estimate risk levels correlated with each production system's net returns, showing which crop enterprise selection are most risk efficient in terms of maximizing profits. SERF graphs illustrate which crop enterprise(s) outperforms other alternatives and the instances where some alternatives may be greater than others relative to a specific risk aversion level. The interpretation of the CE values in terms of wealth over risk using SERF will rank the crop enterprise selection both ordinally and cardinally, indicating which crop enterprise selection provides the grower the highest level of net return (indicated by the highest CE value at each specific risk level). Using data obtained from the construction of the representative farms for each county (parish) in Louisiana and Arkansas, crop enterprise alternatives were analyzed by capturing the grower's share of net returns above variable costs for a specific range of risk aversion coefficients. Those enterprise selections for each region with the highest CE at a specific risk aversion level as being the most desirable (or preferred) option compared to alternative options. Each CE value represents the specific enterprise selection's premium at each risk aversion level.

Louisiana

CEs for the representative farm in Acadia Parish, Louisiana are expressed for conventional variety rice (CN), Clearfield variety rice (CL), hybrid variety rice (HYB), soybeans (SB), and crawfish (CF) and are mapped across a range of ARAC values in Figure 1. ARAC values range from risk neutral (0.000) to risk averse (0.0589) with the highest CE values for each ARAC value indicating which crop enterprise is dominant.

The SERF graph provides ordinal and cardinal rankings across all risk aversion levels. For purposes of crop enterprise selection, each option is fractionally designated followed by a crop abbreviation (*CF*-crawfish, *CL*-Clearfield rice, *CN*-conventional rice, *CR*-corn, *CT*-cotton, *HYB*-hybrid rice, and *SB*-soybeans), this denotes the fractional share of total farm acreage for that given crop enterprise. For the southwest Louisiana farm, option 3/4CN 1/4CF (three-quarters of total acreage being conventional rice with the remaining one-quarter being crawfish) is the most dominant crop enterprise selection as it shows higher CE values across all ARAC values in contrast to other alternative combinations. At a risk neutral level (ARAC = 0.000), option 3/4CN 1/4CF provided the highest premium with a grower's share of net returns above variable costs (CE) of $492.66 per acre. option 1/4CN 1/4CL 1/2CF, at a risk neutral level of ARAC = 0.000, provides the second-best net returns above variable costs (CE) of $436.70 per acre. Option 1/4CN 1/4HYB 1/2CF provides the lowest grower's share of net returns above variable costs (CE) of $426.74 per acre. As risk aversion increases, the grower's share of net returns above variable costs for all other alternative crop enterprises decreases.

At extreme levels of risk aversion where ARAC = 0.0589, option 3/4CN 1/4CF provided the highest premium with a grower's share of net returns above variable costs (CE) of $456.91 per acre. For the same ARAC level, option 1/4CN 1/4CL 1/2CF provides the second-best level of net returns above variable costs (CE) of $399.56 per acre and option 1/4CN 1/4HYB 1/2CF provides the lowest grower's share of net returns above variable costs of all crop enterprise selections at the extreme risk averse level with a CE value of $386.95 per acre.

CEs for the representative farm are calculated for East Carroll Parish, Louisiana for corn (CR), cotton (CT) and soybeans (SB), and are mapped across their corresponding ARAC values in Figure 2. Again, ARACs range in value from risk neutral (0.000) to risk averse (0.0589) with the highest CE values for each ARAC indicating the dominant crop enterprise selection. The SERF graph provides ordinal and cardinal ranking across all levels of risk aversion. option 1/2CR 1/2SB is the most dominant crop enterprise selection as it shows the higher CE values across all ARACs in contrast to the alternative combination.

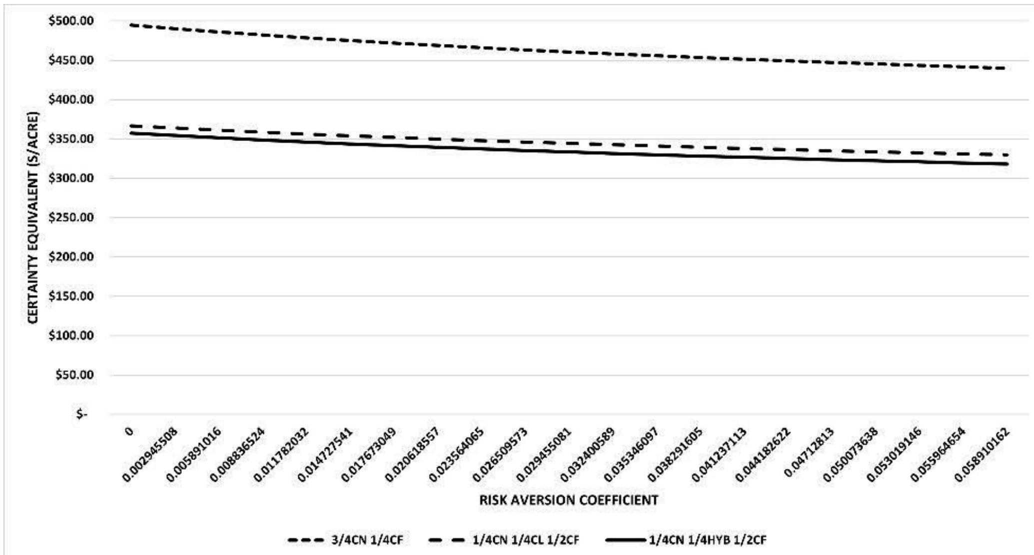

Figure 1. Louisiana, Acadia: Rice, Soybeans and Crawfish using USDA projected commodity prices mean values, SERF graph for economic risk analysis of crop enterprise selections.

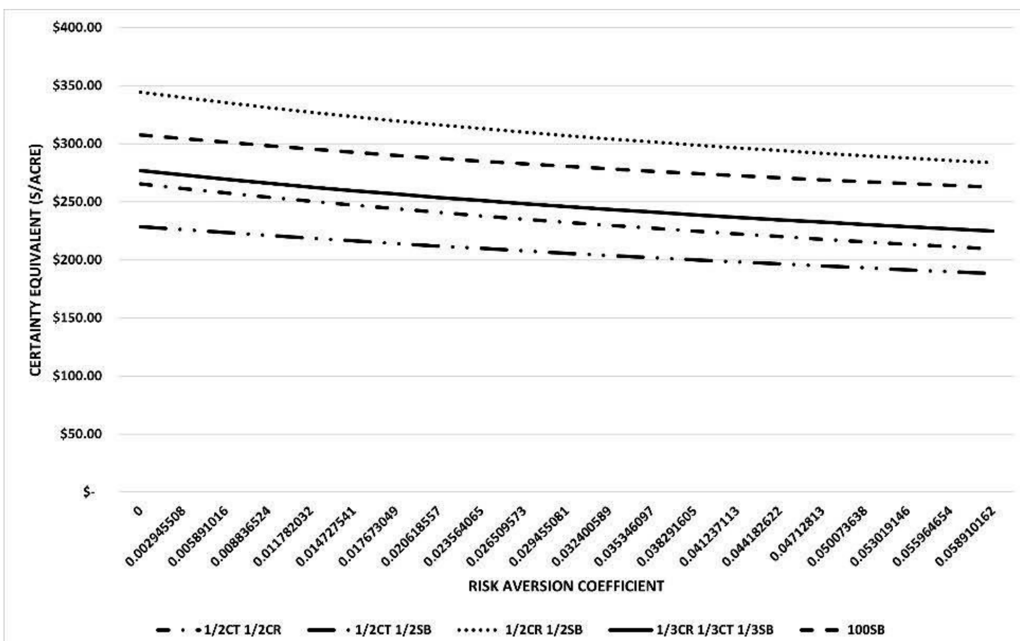

Figure 2. Louisiana, East Carroll: Corn, Cotton, Soybeans, using USDA projected commodity prices mean values, SERF graph for economic risk analysis of crop enterprise selections.

At a risk neutral level of ARAC = 0.000, option 1/2CR 1/2SB provides the highest premium with a grower's share of net returns above variable costs (CE) of $344.58 per acre. option 100SB at a risk neutral level provides the second-best net returns above variable costs (CE) of $307.61 per acre. Option 1/3CR 1/3CT 1/3SB at a risk neutral level of ARAC = 0.000 provide the third-best net returns above variable costs (CE) of $276.77 per acre. Option 1/2CT 1/2CR at a risk neutral level provides the fourth-best net returns above variable costs (CE) of $265.54 per acre. Option 1/2CT 1/2SB provides the lowest grower's share of net returns above variable costs (CE) of $228.57 per acre for a risk neutral ARAC level.

At extreme levels of risk aversion, option 1/2CR 1/2SB provided the highest premium with a grower's share of net returns above variable costs (CE) of $283.61 per acre. Option 100SB at a risk averse level of ARAC = 0.0589 provides the second-best net returns above variable costs (CE) of $262.55 per acre. Option 1/3CR 1/3CT 1/3SB at an extreme risk averse level provides the third-best net returns above variable costs (CE) of $224.81 per acre. At an extreme level of risk aversion, option 1/2CT 1/2CR provides the fourth-best net returns above variable costs (CE) of $209.35 per acre. Option 1/2CT 1/2SB provides the lowest grower's share of net returns above variable costs (CE) of $188.29 per acre for a risk averse level of ARAC.

Arkansas

CEs for the representative farm in Arkansas County, Arkansas are for hybrid rice (HYB), soybeans (SB) and are mapped across a range of ARAC values in Figure 3. ARACs range in value from risk neutral (0.000) to risk averse (0.0589) with the highest CE values for each ARAC indicating the dominant crop enterprise selection. The SERF graph provides ordinal and cardinal ranking across all levels of risk aversion. Option 1/2HYB 1/2SB is the most dominant crop enterprise selection as its CE value is the highest across all ARACs as compared to other alternatives.

At a risk neutral level, option 1/2HYB 1/2SB provides the highest premium with a grower's share of net returns above variable costs (CE) of $217.15 per acre. Option 3/4HYB 1/4SB at a risk neutral level provides the lowest grower's share of net returns above variable costs (CE) of $203.97 per acre. As risk aversion increases, the grower's share of net returns above variable costs for all alternatives decreases.

At extreme levels of risk aversion where the ARAC = 0.0589, option 1/2HYB 1/2SB provides the highest premium with a grower's share of net returns above variable costs (CE) of $95.61 per acre. At the same level of risk aversion (identical ARAC value), option 3/4HYB 1/4SB provides the second-best net returns above variable costs (CE) of $48.53 per acre and the lowest grower's share of net returns above variable costs for all crop enterprise selections at an extreme risk averse level.

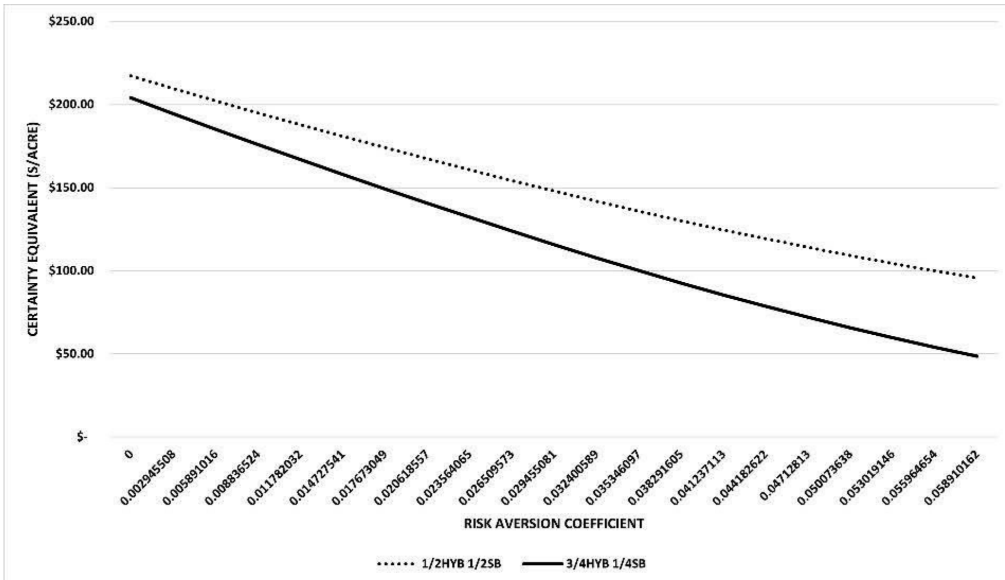

Figure 3. Arkansas, Arkansas: Hybrid Rice and Soybeans, using USDA projected commodity prices mean values, SERF graph for economic risk analysis of crop enterprise selections.

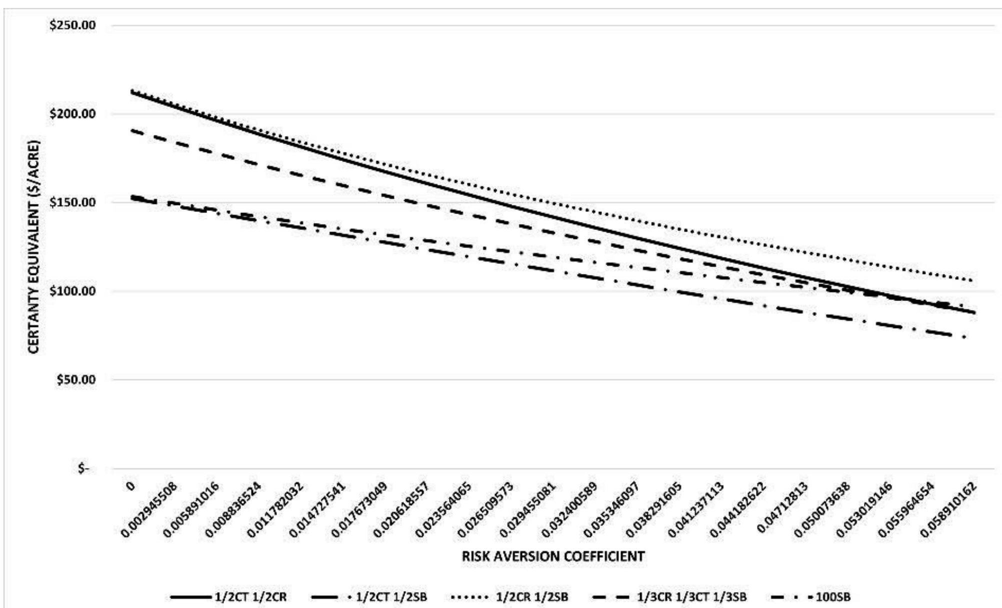

Figure 4. Arkansas, Mississippi: Corn, Cotton, and Soybeans, using USDA projected commodity prices mean values, SERF graph for economic risk analysis of crop enterprise selections.

CEs for the representative farm in Mississippi County, Arkansas are for corn (CR), cotton (CT) and soybeans (SB) and were mapped across a range of ARAC values in Figure 4. Option 1/2CT 1/2CR and Option 1/2CR 1/SB are the most dominant crop enterprise selections as they reflect the highest CE values across all ARACs in contrast to all other alternative combinations.

At a risk neutral level of ARAC = 0.000, options 1/2CT 1/2CR and 1/2CR 1/SB provided the highest premiums with a grower's share of net returns above variable costs (CE) of $213.23 as their CE values were identical. Such outcome indicates that growers would be indifferent between either of these two alternatives at this specific risk aversion level. Option 1/3CR 1/3CT 1/3SB provides the second-best net returns above variable costs (CE) of $190.56 per acre at a risk neutral level. At a risk neutral level, options 100SB and 1/2CT 1/2SB provide the third-best net returns above variable costs (CE) at $153.49 per acre. Since these two options' CE values are identical across all ARAC values, risk neutral growers would be indifferent between these two options. As risk aversion increases, the grower's share of net returns above variable costs for all alternative, decreases. However, when ARAC = 0.0500, options 1/2CT 1/2CR, 1/3CR 1/3CT 1/3SB and 100SB would equally appeal to risk averse growers as they reflect identical CE values of $102.61 per acre.

At extreme levels of risk aversion, option 1/2CR 1/2SB dominates all other alternatives with a CE value of $105.79 per acre. Option 100SB, at a risk averse level of ARAC = 0.0589, provides the second-best net returns above variable costs (CE) of $91.22 per care. At a risk averse level of ARAC = 0.0589, options 1/2CT 1/2CR and 1/3CR 1/3CT 1/3SB provide the third-best net returns above variable costs (CE) of $88.17 per acre for both options. Since both options' CE values are identical, risk averse growers would be indifferent between these two alternatives. The lowest grower's share of net returns above variable costs of all crop enterprise selections at an extreme risk averse level was option 1/2CT 1/2SB. Option 1/2CT 1/2SB is deemed least preferable to growers as it provided the lowest net returns above variables costs (CE) at just $73.41 per acre.

Conclusion

The differences in crop enterprise(s) selection between Arkansas and Louisiana are subtle but distinct. In Louisiana, a predominant conventional rice cultivar and crawfish system (3/4CN and 1/4CF) system generated the highest return for the Acadia Parish farm. The risk premium, expressed as the CE dollar amount between option 3/4CN 1/4CF and the next highest system (option 1/4CN 1/4CL 1/2CF) is significant at approximately $50 per acre. Arkansas, by contrast, favored hybrid rice cultivars along with soybeans (1/2HY and 1/2SY) as it generated higher net returns for the risk neutral grower. Interestingly, as the amount of acreage devoted to hybrid rice cultivars increased (acting to displace soybean acres), the level of grower net returns decreased across all risk aversion levels. The risk premium from moving from a 1/2HYB to a 3/4HYB allocation increased from approximately $10 to $60 per acre as the grower's level of risk aversion increased. To explain the increase in risk premium for the Arkansas rice and soybean farm, it can be inferred that production costs for soybeans are lower compared to other commodities and can provide positive margins when produced in conjunction with rice, a crop that normally entails a higher cost of production and management intensity. It is also noted that a predominant share of Arkansas's rice acreage is devoted to hybrid rice cultivars. The yields for hybrid rice cultivars are greater than yields for both conventional and Clearfield rice varieties but cost more to produce. So, as the level of risk aversion increases for the Arkansas rice grower, the rising risk premium of devoting a greater allocation of the farm's acres (1/2HYB to a 3/4HYB share) to hybrid cultivars introduced more uncertainty into the SERF model, generating lower net returns per acre as a result.

Expanding the representative farm approach to examine non-rice cropping alternatives, results from the East Carroll Parish farm in Louisiana suggest that an evenly allocated corn and soybean rotation (option 1/2CR 1/2SY) was the preferred management plan across all levels of risk aversion, followed by mono-cropped soybeans (option 100SB). The interpretation from the SERF graph implies that as the level of risk aversion increases, the risk premium (expressed as the CE dollar amount between the two alternative systems) decreased from $36.96 at the risk neutral level to $21.06 per acre at the extreme risk aversion level. For the Mississippi Country, Arkansas farm, option 1/2CR 1/2SY generated the greatest level of grower net returns followed closely by option 1/2CT and 1/2CR. However, as the level of risk aversion increased, the risk premium (CE dollar amount between option 1/2CR 1/2SY rotation and option 1/2CT 1/2CR) also increased from $1.25 per acre to $17.81 per acre. This suggests that as growers become more risk averse, option 1/2CR 1/2SY remains the preferred choice over a larger premium. One possible explanation is that higher fertilizer costs associated with both corn and cotton crops can influence a grower's willingness to devote a larger acreage allocation to both crops in periods of energy-related farm input price volatility. As a result, observed decreases in crop selection of cotton and favorable adoption of soybean acres are present in times of input price increases - especially for the risk averse grower. Cotton prices have not experienced the positive price gains that have been observed in both the grain and oilseed markets over the observed period due to cotton's semi-durable nature. This observation suggests that cotton prices are subject to other extraneous macroeconomic factors reflected in economic conditions (e.g., spending activity) surrounding sales of home furnishings and textiles. Therefore, with the absence of a significant price movement in the cotton market, growers would consider a soybean rotation as part of their management plan due to its potential margin. Therefore, the grower would likely only switch their cropping alternatives if expected returns exceeded the premium.

As shown in this study's methodology, both fertilizer and diesel were identified as stochastic variable costs because they comprise a significant portion of the total variable cost of production. Therefore, input price volatility is modeled to capture not only the effect varying input costs have on enterprise crop selection, when coupled with localized price and yield fluctuations, but also net returns per acre as well. The implication of the lowered cost of production input requirements associated with soybeans affording potentially greater net returns is because soybean net returns are relatively insulated from precipitous changes in input costs unlike other commodities. Soybean returns are primarily driven by state prices, yields, diesel, and non-stochastic variable costs (e.g., chemicals and labor). As such, the prevalence of soybeans as an alternative enterprise selection is prominent across all representative farm locations in Louisiana and Arkansas.

Interestingly, in choosing option 100SB, one could infer that because soybeans have a lower total variable cost of production relative to other costs as soybeans are not as input intensive in those inputs directly tied to the energy market (e.g., nitrogen fertilizer), soybeans did not suffer those shock effects associated with swings in energy costs to the extent as corn and cotton. While outside the scope of this study, positive externalities to choosing Option 100SB could also be ascribed to soybeans' positive agronomic impacts on the soil in its ability to fixate nitrogen in soils and its ability to crowd out invasive weed species aiding weed management efforts obviating additional herbicide treatments, which, in turn, helps lower variable costs. A plausible conclusion is that risk averse producers may be more disposed to prioritize soil health in times of commodity price fluctuations. Rotating crops with a high carbon to nitrogen ratio (e.g., corn, cotton, small grains, and rice) with low carbon/nitrogen ratio crops (e.g., soybeans and winter legumes) is highly beneficial for diversity of soil organisms. Crop mixes with different rooting patterns that explore the soil to different depths also are useful for soil improvement. Shallow root systems of grain crops improve soil tilth and increase biological activity to the extent of rooting depth. Deep taproots of crops such as cotton open avenues for deeper penetration of soil organisms and improved soil quality at deeper depths (Hutchinson et al., 2016). This further underscores the desirability that these secondary benefits possessed by growers who seek to merge their respective enterprise crop rotation and agronomic management strategies.

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Learning by the Hour: Student Perceptions on Single-credit-hour Agribusiness and Agricultural Economics Courses

Rachna Tewari, Na Zuo, Joey Mehlhorn, and Maria Bampasidou

Agribusiness and Agricultural Economics programs have implemented single-credit-hour courses to adapt to program requirements and update trainings in essential and specialized student skills. These courses complement student skill advancement, while benefiting students with manageable course loads and flexibility in scheduling. How do these courses fare? What is their value to students? This study presents information on students' opinions on single-credit-hour courses from a study conducted in three agricultural economics and agribusiness-oriented programs that offer single-credit-hour courses. The study was conducted over three semesters from January 2021 to May 2022 and students were surveyed upon completion of the course taken. We found that 57% to 68% of our sample students felt confident in their ability to apply the course information to future work-related assignments. Moreover, students perceived the single-credit-hour course enjoyable, and helpful. Motivation to enroll in single-credit-hour courses was the highest if it was required for the degree. Students' agreement on whether class deliverables were enjoyable or not, student cumulative GPA, and student employment status were among the factors considered for future enrollment in a single-credit-hour course, irrespective of whether it counted towards the degree requirement.

***Key words**:* Agribusiness, Single Credit Hour, Student Perceptions, Undergraduate

Course offerings in undergraduate agribusiness and agricultural economics programs[1] have traditionally consisted of three-credit-hour courses, primarily offered during regular academic semesters. Three-credit-hour courses provide a standard measure for a course offering designed to fit instructor time and effort as it relates to teaching appointments and full-time equivalent (FTE) workloads. However, due to programmatic needs, flexible curricular, and efforts to enhance student skills, to name a few, academic programs deviate from offering solely three-credit-hour courses. Single-credit-courses have been part of academic curricular for years, with some disciplines incorporating them into their general education courses. Single credit laboratory courses are

[1] The umbrella term agricultural economics and agribusiness programs refers to the study/discipline and not to the name of the program or the degree, they confer. As such, for example, food and resource economics, applied economics, etc. that offer agribusiness degrees are also included.

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incorporated in science courses and have been foundational in allowing students to demonstrate mastery of skills and concepts taught in the traditional classroom.[2] Moreover, single-credit-hour courses have been used as special topics courses to dive into essential but fast evolving topics in depth and also in a timely matter (e.g., special topics course on agricultural labor issues and food policies), student competition-related courses (industry related or professional associations) (Bhandari et al., 2013), and service or 'exploration' courses exposing students to new fields of study or careers (Bilder, 2022). As digital credentialing and micro credentials become more popular among industry professionals (AACSB, 2021), short-term or fewer credit hours courses show advantages in training and allowing students to demonstrate specific skills. Single-credit-hour courses can also allow for flexibility to introduce targeted training to students that do not fit into a traditional course format. In agricultural economics and agribusiness programs, in particular, single-credit-hour courses are offered as standalone courses or supplement learning objectives of a three-credit-hour course through labs or similar applied activities.[3] Typically, single-credit-hour courses are highly specialized and focused on singular outcomes, such as mastery of industry required skills/software (e.g., Excel applications), soft skills (e.g., intensive writing (Deans, 2017)) or improving knowledge on a subject matter in agribusiness and agricultural economics allowing for career opportunities (Espey and Boys, 2015).

Due to the perception of single-credit-courses as three-credit-course complements, or in the case of trial and competition courses, as no-repetitive or adaptive course content, single-credit-course related research is limited.[4] To what extent are single-credit courses of interest and value to students? Is the nature of the course; mandatory or elective, new topic or course complement, of importance when students select to enroll in a class? This study aims to understand student perceptions towards these courses. We surveyed students that enrolled in three single-credit-hour classes over three semesters from January 2021 to May 2022, in three different academic departments. We found that 57 to 68 percent of our sample students felt confident in their ability to apply the course information to future work-related assignments. Moreover, students perceived the single-credit-hour course enjoyable, and helpful. Motivation to enroll in single-credit-hour courses was the highest if it was required for the degree. Students' agreement on whether class deliverables were enjoyable or not, student cumulative GPA, and student employment status were among the factors considered for future enrollment in a single-credit hour course, irrespective of whether it counted towards the degree requirement.

Considering the administrative and faculty effort in creating and administering single-credit-hour classes, either this is based on perceived student needs from faculty perspective, increasing pressure during scheduling and opportunities for retaining students or having enough course offerings for on time graduation, we have little documented input from students. To our knowledge, this is the first study that focuses on student perceptions of single-credit-hour courses in

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[2] College Algebra, Physics, Chemistry and Statistics are example of science courses that use a 'lab' component added in the three-credit courses, with many departments offering them as four-credit courses.
[3] Authors' review of available online course catalogs.
[4] Single-credit-courses are subject to student evaluation; however, lab components may not be assessed as a stand-alone part of the course, hence student evaluation results cannot be detangled.

agribusiness, and though our work has limitations, we hope it generates discussion among academics and administrators to better serve their constituents.

Background and Selected Literature

We refer to single-or one-credit-hour courses as a course that meets for less time, usually 50 minutes per week in a 16-week semester schedule, as compared to a full-credit-hour or three-credit-hour courses, which usually meet twice or thrice a week for a total of 150 minutes per week in a 16-week semester. Single-credit-hour courses can also be taught in alternative formats such as compressed part of term or transitory courses between high school and college. The literature on single-credit courses is slim and mostly stems from the STEM disciplines (Pierre et al., 2009). This literature review synthesizes information from agribusiness and non-agricultural economics disciplines.

Why the single-credit-hour course? The purpose.

Single-credit-hour courses contribute to program requirements. In an early study, McCuen (1985) describes single-credit-hour freshman and senior capstone courses as a plausible solution to the issue of general education requirements not meeting the accreditation intent that relates to social sensitivity/ethics among young engineers.[5] Pierre et al. (2009) discuss the development and format of a single-credit-hour laboratory courses in electrical and computer engineering. The idea is to stimulate student curiosity and motivation for varied areas in the discipline early on, as well as to give them a preview of information to be covered later in the program.

In addition, single-credit courses complement skills and course learning objectives. Several of these courses are offered as companions or an extension of a typical three-credit-hour course. In agribusiness and agricultural economics majors, examples include Excel labs that complement farm/agribusiness management, finance, and statistics courses. A direct effect of these courses is the improved understanding of course learning objectives and direct application of knowledge. An indirect effect is the improved performance of students in future and upper-level courses that use these skills. Ricker (1997; 2008), a librarian, discusses faculty experience of co-teaching a one-credit chemistry course with a colleague in chemistry. Positive experiences of teaching the course included better acquaintance with students and being able to assume that the students developed a certain level of library research skills which would benefit their future coursework.

Single-credit-hour courses may be considered as alternatives to three-credit-hour courses. Deans (2017) reports on the effects of a one-credit writing-intensive course in lieu of a standard

[5]Similar examples include the new General Education curriculum in the University of Arizona that has built into it a single-unit course that students take upon their entry into the program and another single-unit course that they take as they complete the program. These courses are meant to bookend the General Education curriculum in a way that promotes student reflection and meaning making throughout their general education experience.

three-hour credit. His findings suggest that well-designed one-credit-hour courses were on par with the quality of deliverables in a standard three-credit-hour course. In his study, four different disciplines were considered, namely Animal Sciences, Nutritional Sciences, Allied Health, and Economics.

Furthermore, single-credit-hour courses may be used as 'exploratory' courses. Some of these courses are built in curricular to introduce industry liaisons and present career paths (Folsom et al. 2004; Bhandari et al., 2013; Bilder, 2022), internships and professional accreditations (Bilder, 2022). Single-credit-hour courses are also used to enhance upper-level skills including research seminars (Chiu et al., 2020). Lastly, single-credit courses can be seen as skill development for graduate students enhancing teaching skills (Zuo, Penn and Asgari, 2018).

On the one hand, single-credit-hour courses benefit students with manageable course loads and flexibility in scheduling. On the other hand, the development and offering of single-credit-hour courses require significant instructor effort (Deans, 2017). Developing a single-credit-hour course is not simply dividing a traditional three-hour course into thirds, the development of the course needs to be focused on conveying content into compressed blocks of time, without overwhelming students. Since time is limited, faculty need a detailed course plan and remain focused on course outcomes. It calls for innovative course designs that provide measurable learning outcomes, balance course contents to maintain student interest and attention span, and ultimately achieve targeted student outcomes. Other factors to consider are course expectations and grading schemes, instructor remuneration based on full time equivalent (FTE) workloads, demand during regular semesters versus summer or other shorter semesters (i.e., Maymester or Jterms), and to ensure that these courses fit into the students' degree requirements as electives or core courses. As with all classes, they need to demonstrate that they meet a need to develop the student into a well-rounded graduate and add to student mastery of the subject matter.

On student course decisions

While the adoption of single-credit-hour courses is justifiable from an administrative and academic perspective, little do we know why students select to take a single-credit course. Few studies have explored the value of single-credit-hour courses with regards to students' attitudes, knowledge acquisition and performance. The results suggest a positive association with single-credit-hour courses that complement or are companions to two or three credit courses. Examples include Jahns et al. (1998) examining knowledge and attitude changes in nutrition concepts and Deans (2017) on motivation and performance in writing intensive courses. Bhandari et al. (2013) and Branan et al. (2018) comment on student increased value and appreciation of partnership, institutional assistance, and motivation of a one-credit hour professional seminar course for doctoral students.

Ognjanovic et al. (2016) use the Analytical Hierarchy Process (AHP) approach to predict student course selection suggesting that the future course selection was determined by students' grade point average in relation to the grades of the courses they are considering for enrollment. A study by Othman et al. (2019) attempts to explore varied fields of decision-making affecting students' class selection and enrolment. The study outlines class selection as a critical decision for students, reflecting their expectations of how it would impact their career goals and paths in the future. Furthermore, it also may affect their academic accomplishment in the program. Moreover, Othman et al. (2019) reveal that the class and lecturer factor, time-space factor, ease and comfort factor, course mate factor and commitment factor greatly influence students' decision-making process during class selection and enrolment. The study further quantified that gender and students' personal attitudes also affected the choice and selection behavior.

Other underlying factors that make students' behavior for class selection and course enrollment critical are directly related to cost-effectiveness and scheduling of course offerings. Attewell and Monaghan (2016) provide positive evidence of on-time completion with students enrolling for 15 credits per semester as a full time and advocate on financially incentivizing these behaviors. Encouraging students to take more credits per semester may be an approach that has negative consequences among them crowding out study time per course and affecting their academic performance (Stinebrickner and Stinebrickner, 2004). Huntington-Klein and Gill (2021) find no evidence that high course loads negatively impact student grades. Early college credit programs are also positively associated with on time degree attainment (Adelman, 1999; Young et al., 2013; Burns et al., 2019). One-credit courses may offer a way to balance credit hour requirements, timely graduation and may come as a lesser load for students. The latter can also apply to transfer students that carry many credits single-credit-hour courses upon enrollment to their new major. This is critical information for higher education administrators.

Study Framework, Methods, and Data

This study is the outcome of a working group of agricultural economists pertaining to the evaluation of academic programs, with an emphasis on single-credit-hour programs. Specifically, this case-study was meant to gauge undergraduate students' perceptions on single-credit-hour programs. All three higher education institutions participating in this study are accredited, with the study being IRB approved (2021-852-E05-4005) in all participating institutions. The academic programs in these institutions are geared towards providing business fundamentals combined with the technical knowledge required for a successful career in the agribusiness industry. The authors were the main instructors of the courses surveyed with multiple years of teaching experience in undergraduate studies.

The courses selected to participate in the study emphasized technical skills and critical thinking. Two of them are considered technical skill-based courses with a focus on practical application of agribusiness concepts using Excel. The third one is a synthesis of economic theory, data collection and data visualization, with policy applications. The size of the sample single-credit-hour courses is small, ranging from 24 to 52 student enrollments per class. The relatively small class size is partly by design given the seating capacity of computer labs and the optimal size of effective hands-on learning in a computer lab environment, and partly due to the elective nature of a course, e.g., targeting a specific student group who are interested in topics in agricultural labor. Table 1 presents more details of the single-credit-hour courses in the sample.

An online survey was designed to examine student perceptions on single-credit-hour courses. The survey instrument also utilized a Likert scale tool to obtain specific responses to certain questions on single-credit courses. The questionnaire was distributed online using a survey link via Qualtrics. All responses to the survey were recorded anonymously. Specifically, the sample consisted of 124 completed student responses across three single-credit courses offered during Spring 2021, Fall 2021, and Spring 2022.

Table 1. Description of single credit hour courses offered at participating institutions.

Institution	Course description	Frequency offered	Enroll	Modality	Incentives to complete the survey & Response rate	Course characteristics
A	Advanced Farm and Ranch Management Lab	Spring and Fall (14-week schedule)	24 (Spring 2021) 28 (Fall 2021)	Offered asynchronous online due to the pandemic; in-person options exist	None Response rate = 67.7%	-3+1 co-requisite where the single credit serves as skill practice lab -Emphasis on applied problem solving in farm management, excel skill development and practice -Financial analysis and linear programming with Excel. -Class project involved a whole farm plan and budget
B	Excel Applications for Economic Analysis	Spring only (7.5-week schedule with 100-minute class time per week)	52 (Spring 2021) 38 (Spring 2022)	Offered asynchronous online in 2021 due to the pandemic; in-person in a computer lab in Spring 2022	Minimal bonus* Response rate = 82.9%	-Stand-alone workshop course -Emphasis on excel skill and practice -Highlights are descriptive statistics and charting with excel -Class project involved a data-focused fact sheet on agriculture and food issues
C	Topics in Agricultural Labor	Fall only (16-week schedule)	24 (Fall 2021)	Offered in-person and online synchronous. Due to the pandemic students were given the option to participate in either format.	None Response rate = 45.8%	-Stand-alone single credit course; First time offered. -Emphasis on critical thinking and synthesis of resources with a focus on labor topics. - The course introduced economic theories, and data sources to address policy topics. - Activities ranged from discussions and forums pertaining to agricultural labor, to Excel use for data visualization and statistics. - Class project involved a theory-data-policy report explaining to a non-academic audience one of the key concepts discussed in class; individual reports were submitted

For example, the policy and language provided to students are "If the response rate reaches 80% by then, the whole class will be granted 5 bonus points in the final grade." The 5 bonus points are equivalent to 0.5% of the overall grade.

The questionnaire was structured around student characteristics and specific questions on single-credit-hour courses. Questions on student characteristics focused on classification (freshman, sophomore, junior or senior), gender, age, current GPA, experience with online learning, and enrollment hours or class load for the semester. Specific questions on single-credit-hour courses explored student experience with single credit courses, motivation to enroll in the course, hours spent each week working on the course outside of class hours, attention span, expected grade, and specific course perceptions, including if the students found the course materials enjoyable, if the activities and exercise in the course helped them learn the course content better, if the amount of information covered was adequate for a single-credit-hour course, if they felt confident in their ability to apply the information learned in this course in future work related assignments, if they will consider taking a single credit hour course in the future, whether it counted towards their degree requirements or not.

The sample consists of five sessions of the three single-credit-hour courses in three semesters. Out of the total of 166 students who enrolled in the sample courses, 124 completed student responses were collected with the response rate of 74.7%. Table 2 summarizes the descriptive statistics and description of variables used in the survey questionnaire.

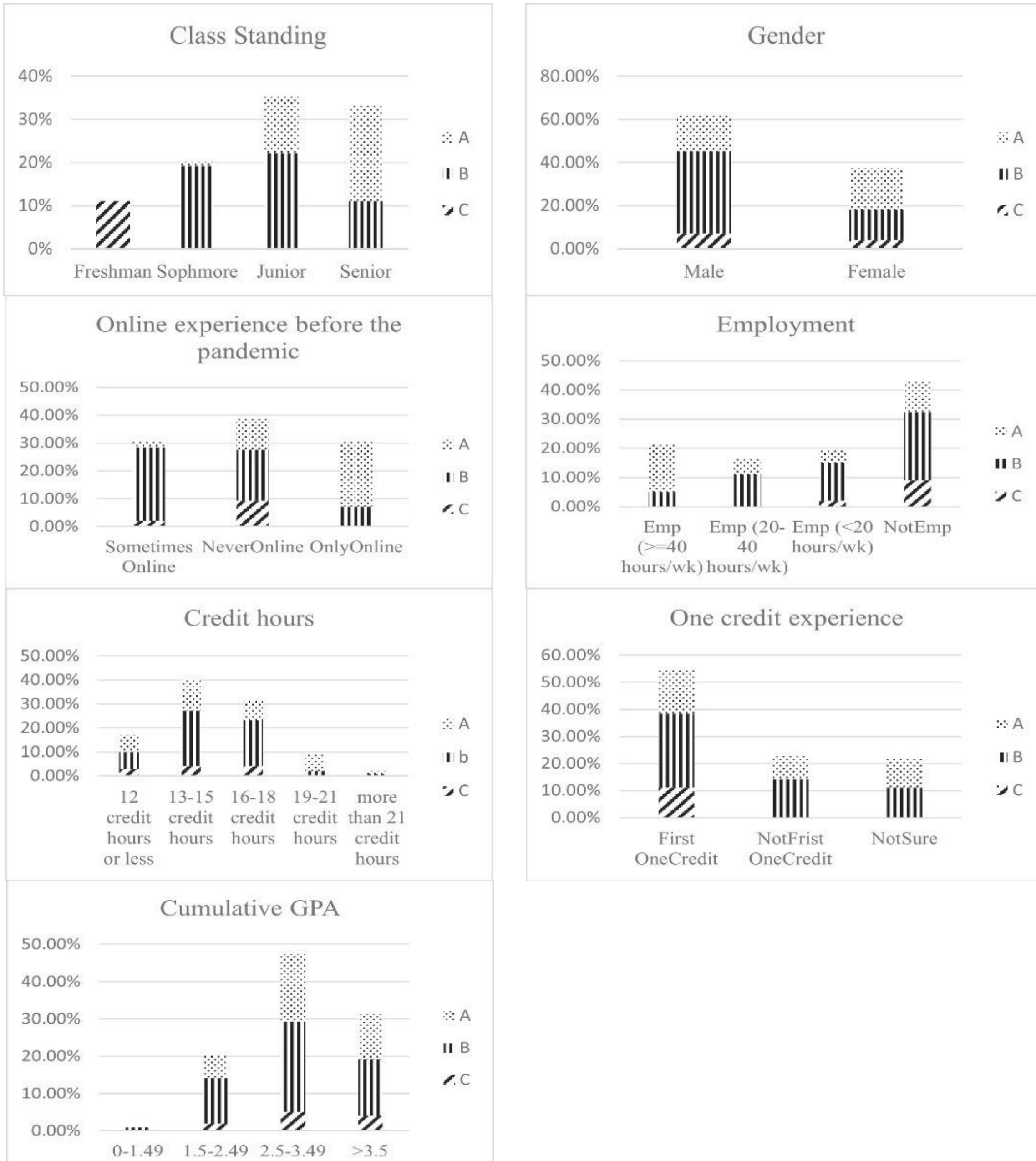

Figure 1. Student demographics, academic characteristics, and online class experience.
(A, B, and C refer to the sample from Institutions A, B, and C, as summarized in Table 1.)

Table 2. Descriptive statistics for the survey data.

Variable	Obs.	Mean	Std. dev.	Min.	Max.
School (0=Institution A, 1=Institution B, 2= Institution C)	124	0.7984	0.5841	0	2
Semester (0=Spring 2021, 1=Fall 2021, 2=Spring 2022)	124	0.7016	0.7858	0	2
Class (1= Freshman, 2=Sophomore, 3=Junior, 4=Senior)	124	2.8629	0.9486	1	4
Gender (1=Male, 2=Female)	124	1.3871	0.4891	1	2
Online (1=On-campus but sometimes take online classes before the pandemic, 2=On-campus and never take online classes before the pandemic, 3=Only take online classes)	123	1.9024	0.762	1	3
Employed (4=Full time employed while attending school (>40 hours per week), 3=Part time employed while attending school (20 to 40 hours per week), 2=Part time employed while attending school (<20 hours per week), 1=Not working currently)	124	2.1532	1.169	1	4
Credit (Total hours enrolled in the current semester of 12 options with 1=Less than 12 hours, 2=12 hours, 3=13 hours, 4=14 hours, … 12 = 21 hours of credits)	124	4.7984	2.4428	1	12
First (First time being enrolled in a single credit hour course; 1=Yes, 2=No, 3=Not sure)	124	1.6532	0.8069	1	3
Hours (Hours spent each week working on the requirements of the single credit hour course)	124	2.9677	1.1821	1	6
Attention Span (ability to focus on the concepts uninterrupted for this single credit-hour course is ____ than a three-credit-hour course in my major (1=Less, 2=Same, 3=More)	114	1.8421	0.7235	1	3
Expected grade (My expected grade in this course is____ (6=A, 5=B, 4=C, 3=D, 2=E, 1=F)	114	5.4912	0.655	3	6
GPA (My current GPA falls in the following range ____ (1=0-1.49, 2=1.5-2.49, 3=2.5-3.49, 4= > 3.5)	124	3.129	0.7322	1	4
Enjoyment (I enjoy the activities/ exercises/ deliverables assigned in this course; 1=Strongly disagree, 5=Strongly agree)	123	3.7073	1.2527	1	5
Helpful (The activities/ exercises/ deliverables assigned are helpful for me to learn the course material/content; 1=Strongly disagree, 5=Strongly agree)	124	3.8306	1.3111	1	5
Content (I feel that the amount of content covered in this course was adequate for a single credit-hour course; 1=Strongly disagree, 5=Strongly agree)	123	3.561	1.438	1	5
Confidence (I feel confident in my ability to apply the information learned in this course in future work-related assignments; 1=Strongly disagree, 5=Strongly agree)	124	3.7742	1.2805	1	5
Enroll_required (I will consider taking a single credit-hour course in the future, if it counts towards my degree requirements; 1=Strongly disagree, 5=Strongly agree)	124	3.6613	1.3548	1	5
Enroll_unrequired (I will consider taking another single credit-hour course in the future, even if does not count towards my degree requirements; 1=Strongly disagree, 5=Strongly agree)	123	3.1382	1.363	1	5

Figure 1 shows frequency distribution comparisons of the student sample. In summary, a typical student from our sample is male, has junior class standing, and is not currently employed.

Regarding online class experience and academic characteristics, a typical student takes classes on-campus, had no prior experience with online classes before the pandemic, is enrolled in 13-18 credit hours each semester, and has a cumulative GPA between 2.50 to 3.49. Also, most students in our sample were enrolled for the first time in a single-credit-hour course during the semesters when the survey was conducted for the study.

Empirical Model

We further investigate factors that affect student decisions on whether to take a single-credit-hour course in the future based on the survey data. Two dependent variables are student responses to the questions "I will consider taking a single credit hour course in the future, if it counts towards my degree requirements" (Y_1) and "I will consider taking another single credit hour course in the future, even if it does not count towards my degree requirements" (Y_2). The discrete choices from the survey are logically ordered, where one refers to "strongly disagree" and five refers to "strongly agree". Thus, we adopt an ordered logit model to estimate changes in the dependent variables (Greene, 2012). Assume that one latent preference, Y*, varies continuously in the space of individual utility and underlies students' discrete responses, Y, in the survey, as shown in equation (1). Then:

$$(1) \qquad Y_i^* = \beta_1 Enjoy_i + \beta_2 Helpful_i + \beta_3 Content_i + \beta_4 Confident_i + \boldsymbol{X\beta} + \mu_i,$$
$$Y_i = j \text{ } if \text{ } \gamma_{j-1} < Y_i^* < \gamma_j, j = 1,2,3,4,5.$$

Y* is the continuous student attitude towards whether to take a single-credit-hour course in the further or not. The parameter γ_j is the unobserved cut points to convert the continuous latent preference into discrete responses in the five scales (*j*). Two groups of explanatory variables are included in the model. One group measure students' perceptions of their experience in a single-credit-hour course. For example, to what degree the student enjoyed the course ($Enjoy_i$), found the deliverables assigned helpful ($Helpful_i$), felt the course content adequate for a single-credit-hour course ($Content_i$), and felt confident in one's ability to apply the information learnt ($Confident_i$). Another group of variables controls for student and course characteristics summarized in the vector ***X***. These control variables include total hours spent weekly on the single-credit course, student's expected grades and attention span in the single-credit course. Moreover, we used dummy variables to account for other explanatory variables, particularly whether it is the first time enrolled in a single-credit-hour course, how often the student takes online classes, GPA level, work status, gender, school, and the semester dummies. The effects of explanatory variables are given by the coefficients βs estimated with an ordered logit model (equation 2).

$$(2) \qquad P(Y_i = j|x) = F(\beta_1 Enjoy_i + \beta_2 Helpful_i + \beta_3 Content_i + \beta_4 Confident_i + \boldsymbol{X\beta})$$

where $F(\cdot) = L\ (\omega) \equiv \frac{e^{\omega}}{1-e^{\omega}}$ and $j = 1,2,3,4,5$.

The probability of having $Y_i = j$ conditional on the vector x corresponds to a standard logistic distribution function, $L\ (\omega)$. Robust estimators of variance are applied.

Figure 2. Student perceptions of single credit hours courses and motivation to enroll.

Results

How do students perceive the value of one-credit hour courses?

In the survey, we asked student perceptions of their experience in a single-credit-hour course. For example, to what degree the student enjoyed the activities/ exercises/ deliverables assigned in the course ($Enjoy_i$), found the deliverables assigned helpful ($Helpful_i$), felt the course content adequate for a single-credit-hour course ($Content_i$), and felt confident in one's ability to apply the information learnt ($Confident_i$). Figure 2 depicts students' perceptions of the value of single-credit-hour courses, enrollment decisions in future single-credit-hour courses based on degree requirements, and motivation to enroll in single-credit-hours courses. In our sample, 65 percent agree that they enjoy the course deliverables, and about 68 percent indicated that the assigned course activities and exercises assisted them in learning the course material. 57 percent agreed that the amount of content covered in the course was adequate for a single credit hour course, while 66 percent felt confident in their ability to apply the course information to future work-related assignments (Panel A of Figure 2).

Furthermore, as indicated in Panel B of Figure 2, 59 percent stated that they would consider taking a single credit hour course in the future if it counts towards their degree requirements, while only 41 percent indicated that they would consider taking another single-credit-hour course in the future, even if it did not count towards their degree requirements. Motivation to enroll in single credit courses was the highest if it was required for the degree and declined successively in the following order: if the course topics would potentially be beneficial to their careers, course fits the schedule, was interesting, or was needed for semester hours.

What drives students' decisions on whether to enroll in a single-credit-hour course in the future?

We further estimate two ordered logit regression models to examine factors affecting student perceptions for enrolling in a single-credit-hour course in the future if the course would count versus would not count towards their degree requirements. We examined if these perceptions were affected by student experience in current single-credit-hour course, student demographics, academic characteristics, online class experience, and other factors that potentially impact student learning.

Table 3 summarizes the ordered logit analysis results regarding two dependent variables. Results for the dependent Likert scale variable "I will consider taking a single-credit-hour course in the future, if it counts towards my degree requirements" are presented in column (1) and (2) of Table 3. It was found that students' experience with the single-credit-hour course significantly affected their enrollment decisions with degree requirements. Students who found the class content adequate and reported confidence in applying learnings in a single-credit-hour course are significantly more likely to consider taking a single-credit-hour course in the future if it counts towards the degree requirements. Significance was also noted for attention span, the cumulative GPA, student class stands, and their employment status. The results suggest that students who think their ability to focus on the concepts uninterrupted for the single-credit-hour course is more than a three-credit-hour course are more likely to consider taking a single-credit-hour course with the degree requirements. Students with higher cumulative GPA are less likely to consider taking a single-credit-hour course with the degree requirements, compared to students with lower cumulative GPA, holding others constant. Also, even if it counts towards the degree requirements, Junior and Senior undergraduate students are less likely to enroll in a single-credit hour course than Freshman and Sophomore students, and students who work between 20 to 40 hours per week are less likely to enroll in a single-credit hour course than not-working students. Finally, student experiences with single credit hour courses and online courses were also significant factors.

Table 3. Ordered logit analysis on student decisions.

Variable/Item	Y1		Y2	
	(1)	(2)	(3)	(4)
Enjoyment	0.675*	1.14	0.696**	1.075**
	(0.346)	(0.778)	(0.311)	(0.496)
Helpful	0.438	0.012	-0.169	-0.401
	(0.306)	(0.537)	(0.258)	(0.302)
Content	0.484*	0.836**	0.243	0.269
	(0.261)	(0.351)	(0.179)	(0.246)
Confidence	1.158***	1.355**	0.158	0.275
	(0.366)	(0.637)	(0.304)	(0.475)
Hours		0.304		-0.113
		(0.254)		(0.213)
Expected grade		0.326		-0.756
		(0.587)		(0.779)
Attention Span		1.131**		0.688*
		(0.564)		(0.369)
D. First = yes (benchmark)				
D. First = No		0.993*		0.754
		(0.588)		(0.548)
D. First = not sure		1.289		1.566**
		(1.031)		(0.749)
D. GPA = [0, 1.49] (benchmark)				
D. GPA = [1.5, 2.49]		-4.621***		15.642***
		(1.643)		(1.43)
D. GPA = [2.5, 3.49]		-4.547***		16.252***
		(1.723)		(1.422)
D. GPA > 3.5		-4.546**		15.680***
		(1.911)		(1.473)
D. Employed = not work (benchmark)				
D. Employed = work < 20 hours per week		0.681		2.105***
		(0.695)		(0.602)
D. Employed = work 20 to 40 hours per week		-1.467*		0.873
		(0.789)		(0.773)
D. Employed = work >40 hours per week		-1.362		1.330*
		(1.227)		(0.771)
D. Online = sometimes enroll online course (benchmark)				
D. Online = never online		-1.428*		-3.203***
		(0.813)		(0.78)
D. Online = only online		-1.26		-1.623**
		(0.942)		(0.643)
D. Class = Freshman (benchmark)				
D. Class = Sophomore		-2.61		-2.604
		(1.641)		(1.634)
D. Class = Junior		-2.709*		-2.936*
		(1.513)		(1.759)
D. Class = Senior		-3.879**		-4.165**
		(1.755)		(2.025)
School		-2.247**		-1.816**
		(1.026)		(0.749)
N	123	105	122	105
Other controls	No	Yes	No	Yes
Pseudo-R2	0.418	0.556	0.099	0.301
Log-likelihood-value	-104.981	-66.637	-173.941	-115.799

*Notes: 1. Y1 is the dependent variable of student responses in five scales to "I will consider taking a single credit hour course in the future, if it counts towards my degree requirements". Y2 is the dependent variable of student responses in five scales to "I will consider taking another single credit hour course in the future, even if it does not count towards my degree requirements." 2. D. indicates dummy variables. 3. Other control variables include student gender and class dummies. 4. Robust standard errors are in parentheses. 5. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.*

The ordered logit analysis results for the dependent Likert scale variable “I will consider taking a single credit-hour course in the future, if it does *not* count towards my degree requirements” are presented in columns (3) and (4) of Table 3. In the scenario that the degree requirement condition is dropped, and a single-credit-hour course is elective for students, only the student perception on whether they enjoyed a single-credit-hour course stays as a significant factor while other perceptions on content or confidence became insignificant. Student cumulative GPAs continue affecting their enrollment decisions significantly, yet with an opposite direction in its effects, comparing to the previous scenario: students with higher cumulative GPA are more likely to consider taking a single-credit-hour course in the future even if it does not count towards the degree requirements, holding others constant. Academically successful students seem to appeal to a single-credit-hour course as an elective option, which may be driven by interests and enjoyment, as compared to fulfilling a degree requirement. It was found that students’ employment status, perceptions of their attention span, their experience with the single credit hour course and online courses in general, as well as student class standing also impacted the results significantly.

Conclusions and Discussion

Higher education institutions adapt their education programs to cater to the needs of a changing student body. The ‘traditional’ in person three-credit course, though a predominant form, has been complemented and in some cases replaced by online, hybrid, and alternatives format courses. In addition, programs have explored alternative course lengths (e.g., four-credit hour courses, flexible credits, and single-credit-courses). Of course, universities must consider what works best for them and their students. Using alternative course lengths and formats could become more acceptable among students and industry due to the growing acceptance of micro credentialing and other industry short courses. Digital credentialing has become more popular among industry professionals (AACSB, 2021), and this trend could reinforce the acceptance of short-term or fewer credit hours courses that develop and allow students to demonstrate specific skills. Single-credit-hour courses can also allow for flexibility to introduce targeted training to students that do not fit into a traditional course format.

This study attempts to examine student perceptions of single-credit-hour courses in undergraduate Agribusiness and Agricultural Economic programs. With evidence from three participating institutions offering single-credit-hour courses in the Agribusiness and Agricultural Economics programs, we specifically explore how student characteristics, student employment status, student prior experience with similar courses, and the overall student experience in the single-credit-hour course impacts their future decisions to enroll in such courses. Students’ agreement on whether class deliverables were enjoyable or not, cumulative GPA, student class standing, their experience with single credit hour courses and online courses in general, as well as student employment status, are some factors that affect their intentions on future enrollment in a single-credit hour course, irrespective of whether it counted towards the degree requirement. Distinguishably, when the single credit hour course does count towards student degree requirements, students who found the class content adequate, reported confidence in applying learnings in a single-credit-hour course, and are with lower reported GPA are significantly more likely to consider taking a single-credit-hour course in the future. While when the single credit hour course does *not* count towards student degree requirements, only the student perception on whether they enjoyed a single-credit-hour course acts as a significant factor and students with higher GPA are more likely to enroll in a single credit hour course as an elective course in the future.

The study also faces several limitations. First, it focuses on three single-credit-hour courses (five sessions) at three different universities. Although the participating universities include both land grant and non-land grant institutions, the sample size and sample representation respectively could be limited. Second, the study period from fall 2021 and spring 2022 further coincides with the beginning of the pandemic, which adds additional caveats in students' perceptions. Finally, while all student respondents in the sample take both single-credit-hour courses and traditional three-credit-hour courses in their studies, future studies could further investigate whether students who enroll in single-credit-hour courses are significantly different from those who only enroll in three-credit-hour courses. Besides the students' perspective that this study has focused on, the most effective pedagogy and teaching practices in single-credit-hour courses could be further examined in future studies. In addition, the instructor perspectives regarding time and effort in designing and teaching single-credit-hour courses, as well as the administration considerations in assigning teaching FTEs are of importance in shedding light on the role of single-credit-hour courses in a program curriculum.

We believe that this study could serve as a springboard for further in-depth investigations into student learning in single-credit-hours courses. Strategic thinking and planning by programs and institutions to offer alternative credentials will continue to emerge as one of the key determinants for program success, especially in meeting industry needs. Therefore, findings from this study could motivate agribusiness programs to develop new and innovative single-credit-hour courses to fill skill gaps in the curricula and provide flexibility in course scheduling during regular, part of term, summer, or winter semesters.

From prior experience of teaching single-credit-hour courses, we notice an overall positive student experience and student appreciation of focused skills' training in single-credit-hour courses. With the growing popularity of such courses, this study should generate interest among instructors in agricultural economics and agribusiness programs to better understand student perceptions of their own learning, and the most effective pedagogy techniques as used in single-credit-hour courses.

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