Crop rotations and risk management for Mississippi soybean producers, 28-2019

Annual Report

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BACKGRAUND AND OBJECTIVE(S)

Crop rotations are economically significant on both the mean and variance of expected crop yields. This is because an effective crop rotation reduces year-to-year pest pressure, replenish soil nutrients, and increase plant vitality. Soybeans play a unique role in these rotation schemes by fixing atmospheric nitrogen into the soil. In the research, we study the role of crop rotations in farmers' risk management decisions. Specifically, we aim to answer the question: as farmers face unknown future prices, unpredictable weather, and uncertain yields, how do crop rotations' agronomic effects impact farmers' optimal planting decisions? And beyond that: what is the economic value of optimizing crop rotations for a soybean farmer?

To answer these questions, we conduct a statistical analysis via experimental data collected by Mississippi State University Professor Wayne Ebelhar of the Delta Research and Extension Center. We first incorporate these data into an econometric fixed-effects model that controls for observable and unobservable variables affecting crop yield and thereby we isolate the effect of various crop rotation schemes on both the mean and variance of crop yield. We next use these results to models of risk management to determine "optimal decision rules" for soybean farmers by using Modern Portfolio Theory (MPT) models. We aim to answer that how different expectations about future crop prices affect a farmer's optimal planting decisions. Such findings should be directly applicable to Mississippi soybean growers, and easily integrated into existing extension programs or publications. Indeed, the results of my proposed research will provide farmers with information designed to help them maximize both current and future profits.

In summary, the research has two overarching objectives: (1) to quantify the effect of different crop rotation schemes on the mean and variance of crop yield, and (2) to integrate these effects into models of farmer risk management. Objective 1 will help Mississippi soybean producers increase their yields and lower their uncertainty, thereby increasing their revenues and lowering their risk. Objective 2 will provide Mississippi soybean producers with useful decision rules for optimal planting decisions. In both cases, soybean growers should be able to realize increased profits by utilizing my findings.

REPORT OF PROGRESS/ACTIVITY

Objective 1: Quantifying the effect of different crop rotation schemes on mean and variance of crop yield.

Crop rotation studies design their experiments by implementing different crop rotation schemes on co-located testplots that are given equal treatment by the researcher. By varying crop rotations but keeping soil type, input use, and irrigation timing constant, the researcher can isolate the "crop rotation effect" from other determinants of crop yield. In practice, agronomists generally average their findings over different growing conditions and different years to estimate an "average treatment effect" (ATE) of any particular crop rotation scheme. This ATE is scientifically valid and can be reconstructed using econometric techniques. However, this approach discards significant variation across different underlying management practices. The fixed-effect econometric model takes advantage of the abundant wealth of data collected throughout the relevant field trial.

In the most general case, the fixed-effect econometric model follows the following form:

$$y_{it} = \alpha_i + \gamma_t + \beta \boldsymbol{X}_{it} + \varepsilon_{it}$$

where y_{it} represents the yield on field *i* in year *t*, α_i represents the inherent productivity of field *i* (its "fixed effect"), γ_t represents the average productivity of year *t*, $\beta \boldsymbol{X}_{it}$ represents the effects of different management practices on field *i* in year *t* (such as fertilizer use), and ε_{it} represents an error term that captures any contributions to yield not captured by other variables. In order to analyze crop rotation effects, we include an additional term, R_{it}, that represents the crop rotation history of field *i* in year *t*. The variable of interest is then the R_{it}, which would explain rotations' effects net of other drivers of crop yield. Additionally, this effect is estimated with some variance, allowing us to observe crop rotations' effects on the variability of expected crop yield.

To fit the fixed effect model as well as the MPT model, we data from the Centennial Rotation Experiment located at the Mississippi State University Delta Research and Extension Center in Stoneville, Mississippi. The dataset is developed and designed for the 8-acre Centennial Rotation. The Centennial Rotation received its name due to the fact the experiment is a 100-year experiment and was created on the 100th anniversary of the extension center. The main advantage of this study is that each state of each rotation is observed yearly, which leads to a quick turnaround for analysis after only one year. The Centennial Rotation is similar to the Morrow Plots, located on the campus of Illinois University at Urbana Champaign because they both use different variations of crop rotations for several crops. Also, the Morrow Plots have been studied over a lengthy duration similar to the Centennial Rotation, unlike most previous crop rotation studies. However, the Morrow Plots contain crops that are not relevant to the Mississippi Delta region, therefore making the Centennial Plot compatible with the goal of our research.

The three crops observed in this study are soybeans, corn, and cotton. The Centennial Rotation is based around cotton because cotton was the more dominant crop in the Mississippi Delta at the start of this experiment. According to Mississippi State Extension, corn, cotton, and soybeans were responsible for generating approximately $2 billion to the state of Mississippi in 2018. The agriculture industry itself generated around $7.7 billion for the state of Mississippi. Therefore, these three crops are significant to the state and the producers as a whole.

The Centennial Rotation consists of six different rotations: 1) continuous Cotton, 2) a Corn/Cotton two-year rotation, 3) a Corn/Cotton/Cotton three-year rotation, 4) a Corn/Soybean two-year rotation, 5) a Soybean/Corn/Cotton three-year rotation, and 6) a Soybean/Corn/Cotton/Cotton four-year rotation. Again, this experiment is novel because each state of each rotation is observed each year. Each state is referred to as a "treatment" and there are fifteen total treatments in this study. Table 1 displays the layout for each treatment of each rotation from the start of the experiment up to the current year of our data.

Objective 2: Integrating crop rotation effects into models of farmer risk management.

The main goal of estimating the efficiency frontier via the MPT model is to find all the possible set efficient portfolios. The efficiency frontier is a graph that consists of expected returns of the combination of mean crop yields against the risk levels. Risk levels are commonly referred to as variance or standard deviation. The x-axis of the efficiency frontier is the risk levels or variation, while the y-axis is the expected return of the set of portfolios. Any portfolio that is not on this line is considered not optimal and should not be considered to maximize profit or minimize variance. The expected return is calculated by the mean yield for each crop multiplied by the crop price. Profit data is beneficial because we want our output to be relatable to farmers, and it is comparable across all our crops.

The MPT efficiency curve can be solved using several series quadratic programming problems. According to Markowitz (1952), there are two ways to solve for the efficiency frontier: maximize mean crop yield or minimize crop variance. In this paper, we are going to solve by minimizing the variance, or risk. To do that, we will set up our problem by the following:

$$\min \sigma^2_{p,x} = \boldsymbol{x}'\boldsymbol{\Sigma}\boldsymbol{x}$$

which is subject to three constraints:

$$\boldsymbol{\mu_p} = \boldsymbol{x}'\boldsymbol{\mu} = \boldsymbol{\mu_{p,0}}$$

$$\boldsymbol{x}'\boldsymbol{I} = \boldsymbol{I}$$

$$x_i \geq 0 \ (i = 1, \dots, N)$$

where $\boldsymbol{\mu_{p,0}}$ represents a target level of variance (risk), which is determined by multiplying $\boldsymbol{x}'$(vector of shared wealth invested in asset i) by $\boldsymbol{\mu}$ (vector of expected returns on the assets of a portfolio), $\boldsymbol{I}$ is the identity matrix consisting of the shared wealth (percentages) of each asset in a portfolio adding up to 1, $x_i \geq 0$ is a non-negativity constraint to keep all the assets positive since a person cannot take a negative position in agriculture.

For our model, our data consists of corn, cotton, and soybeans, but it is limited because it does not contain every possible crop history for the three crops we are analyzing. We assume an agricultural producer is going to either minimize their risk or maximize their profits. With our data set, we make two key assumptions: 1) an agricultural producer knows their field history up to three years back or 2) an agricultural producer will not know its field history at all. There are four different crop histories we concentrated on: unknown, one-year back, two-year back, and three-year crop histories. Our data set covers a wide range of crop histories that allows us to analyze multiple scenarios to generate the best outcomes to aid producers in the decision-making process.

As mentioned earlier, our output will yield different combinations of weights of each crop. By having a large scale for expected returns and variance, our model is capable of combatting many different preferences from a farmer. The different outcomes generated from our results are the optimal percentage levels of each crop to plant in order to maximize mean yield at set risk level.

Impacts and Benefits to Mississippi Soybean Producers

The research is beneficial to the Mississippi soybean industry in two ways. First, the findings will provide current soybean producers with easily-accessible information about how specific crop rotation schemes can increase their soybean yields and reduce the variability of their soybean yields. This will increase existing soybean producers' revenues. Second, the study allows us to produce decision rules for producers that balance the risk and reward of different potential rotation schemes. This may indicate that other producers could benefit from incorporating soybeans into their own crop rotation schemes – thereby increasing the overall number of Mississippi soybean producers. One reason to think this may prove true is that soybeans, as a legume, are able to fix atmospheric nitrogen into the soil.

End Products–Completed or Forthcoming

A Graduate Research Assistant (GRA) Masters student Ben Bradley in the Department of Agricultural Economics primarily conducts the study under the supervision of Drs. Stevens and Park. Ben Bradley presented the preliminary results at the 2020 Southern Agricultural Economics Association (SAEA) annual meeting, which was held in Louisville, KY.

To complete the research, however, this research project requires an accurate mathematical algorithm to obtain a global optimum mean-variance frontier under the MPT. Therefore, we have tested a prototype computer code several times by using Monte-Carlo simulation data. However, the real data we obtained has more noise than we expected, so that we need to modify our code a bit more. Fortunately, we are now underway to resolve the problem. Therefore, we requested No Cost Extension to ensure the completion of the research. The extended end date is June 30, 2020.

Table 1: Crop Rotations Chart Table 1: Crop Rotations Chart

TRT	SEQUENCE	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	Continuous Cotton	COT	COT	COT	COT	COT	COT	COT	COT	COT	COT	COT	COT	COT
2	Corn/Cotton	COT	CRN	COT	CRN	COT	CRN	COT	CRN	COT	CRN	COT	CRN	COT
3	Corn/Cotton	CRN	COT	CRN	COT	CRN	COT	CRN	COT	CRN	COT	CRN	COT	CRN
4	Corn/Cotton/Cotton	CRN	COT	COT	CRN	COT	COT	CRN	COT	COT	CRN	COT	COT	CRN
5	Corn/Cotton/Cotton	COT	CRN	COT	COT	CRN	COT	COT	CRN	COT	COT	CRN	COT	COT
6	Corn/Cotton/Cotton	COT	COT	CRN	COT	COT	CRN	COT	COT	CRN	COT	COT	CRN	COT
7	Corn/Soybean	CRN	SB	CRN	SB	CRN	SB	CRN	SB	CRN	SB	CRN	SB	CRN
8	Corn/Soybean	SB	CRN	SB	CRN	SB	CRN	SB	CRN	SB	CRN	SB	CRN	SB
9	Soybean/Corn/Cotton	SB	CRN	COT	SB	CRN	COT	SB	CRN	COT	SB	CRN	COT	SB
10	Soybean/Corn/Cotton	COT	SB	CRN	COT	SB	CRN	COT	SB	CRN	COT	SB	CRN	COT
11	Soybean/Corn/Cotton	CRN	COT	SB	CRN	COT	SB	CRN	COT	SB	CRN	COT	SB	CRN
12	Soy/Corn/Cot/Cot	SB	CRN	COT	COT	SB	CRN	COT	COT	SB	CRN	COT	COT	SB
13	Soy/Corn/Cot/Cot	COT	SB	CRN	COT	COT	SB	CRN	COT	COT	SB	CRN	COT	COT
14	Soy/Corn/Cot/Cot	COT	COT	SB	CRN	COT	COT	SB	CRN	COT	COT	SB	CRN	COT
15	Soy/Corn/Cot/Cot	CRN	COT	COT	SB	CRN	COT	COT	SB	CRN	COT	COT	SB	CRN

Table 2: Total Possible Crop Histories

	Two years ago	Cotton			Corn			Soybeans		
	Three years ago	Cotton	Corn	Soybeans	Cotton	Corn	Soybeans	Cotton	Corn	Soybeans
One year ago	Cotton	Ct	Cr, SB		Ct, Cr		Ct, SB			
	Corn	Ct	Ct					Ct	SB	
	Soybeans	Cr	Cr				Cr			

Figure 1: Experimental Plot Soil Layout

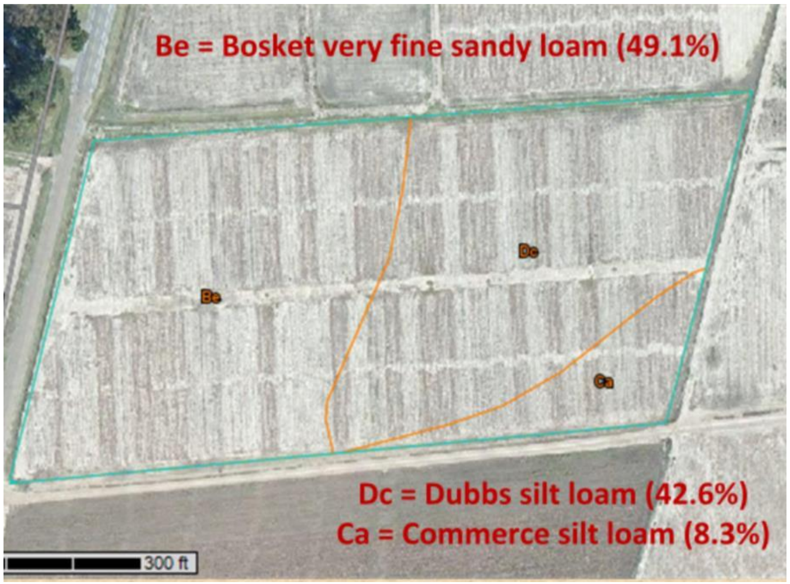

Figure 2: Example of 2013 Corn/Cotton Rotation Layout

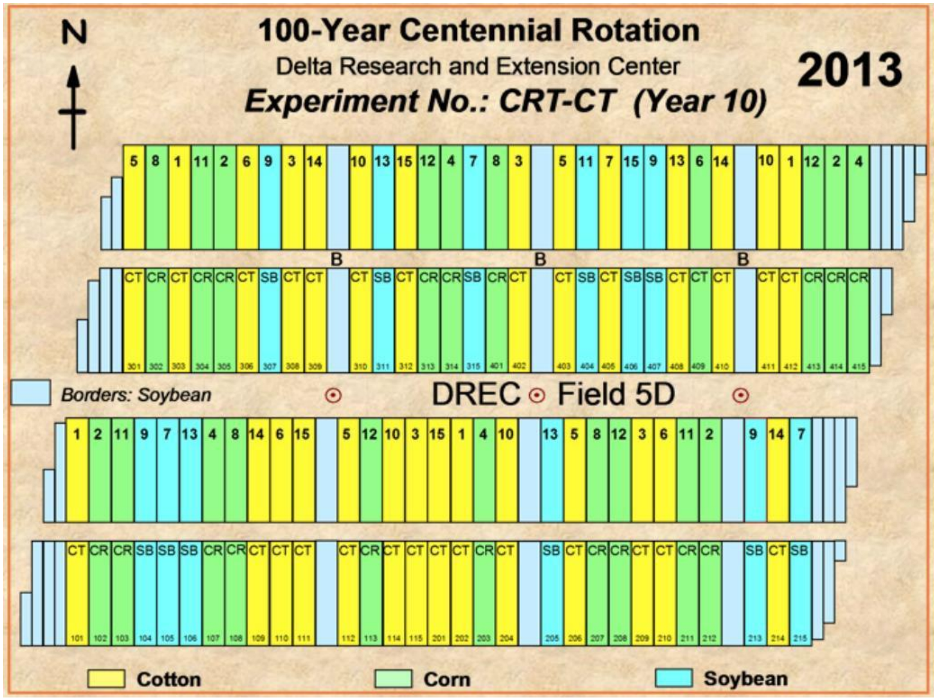

Figure 3: Mean Corn Yields Summary Statistics

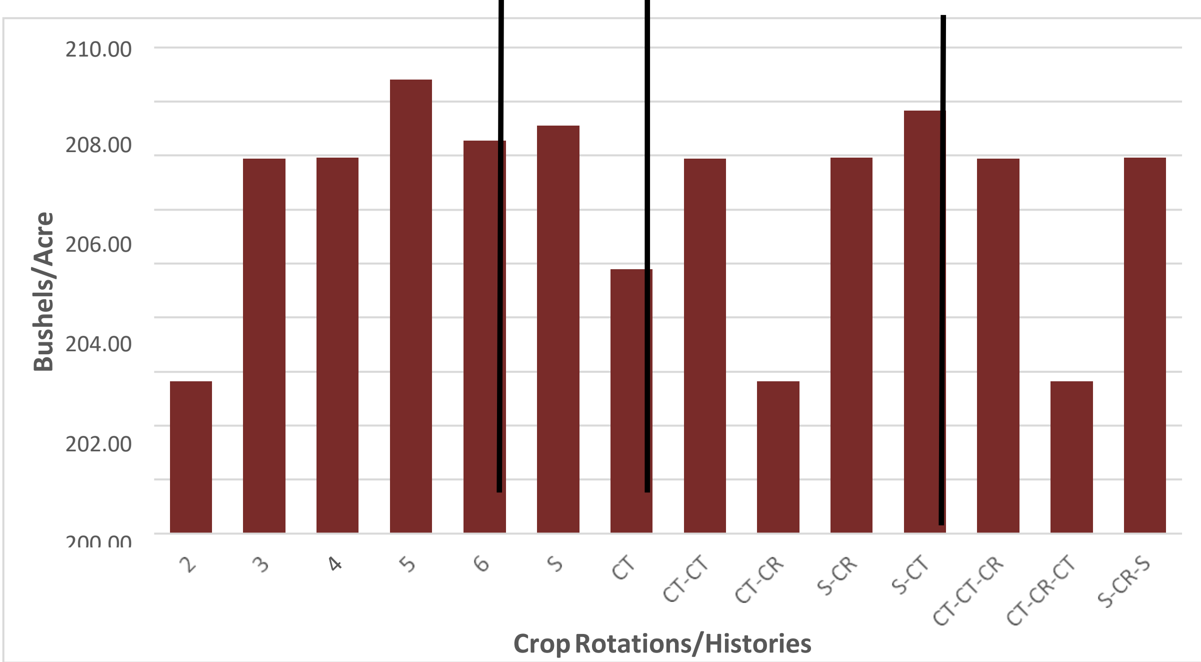

Figure 4: Soybeans Mean Yield Summary Statistics

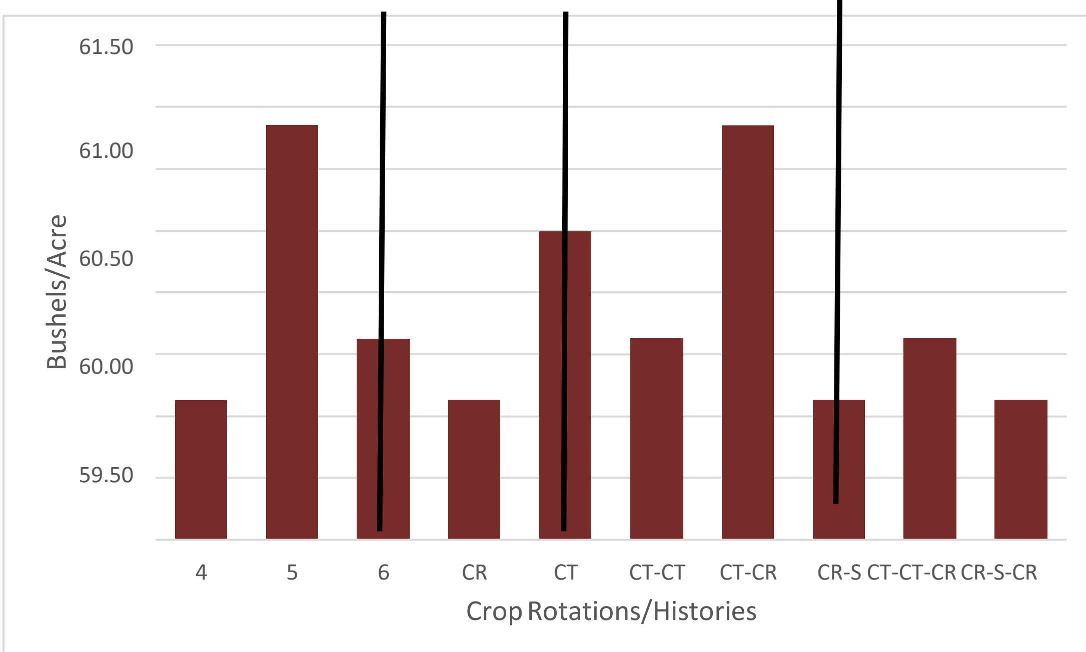

Figure 5: Cotton Mean Yi