Essays on Using Experimental Agronomic Data to Solve Practical Cropping Decision Problems

by

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Abstract

Across the United States, agronomic research is being conducted that provides agricultural producers with new cropping options; however, without having insight into the profitability or risk associated with the options, producers may not make the optimal decision for their operation. This dissertation consists of three essays in applied agricultural economics utilizing experimental agronomic data to solve practical cropping decision problems.

The first chapter examines the impact of row spacing, tillage, and seed traits on cotton profitability in Alabama, and estimates profits using an application of a single equation and a multi-equation approach. Overall, estimating a single equation profit function and constructing profit from multi-equation response functions produced similar results. Non-transgenic seed planted with standard and narrow spacing utilizing both conservation and conventional tillage were in the top five most profitable production options regardless of rainfall amount and estimation method.

The second chapter determines the optimal crop rotation for a peanut and cotton producer in Alabama under alternative land tenure arrangements considering previous land use and Markovian prices. The decision to adopt a rotation instead of monoculture is heavily influenced by expected yield, production costs, and expected prices. The land ownership scenario has the lowest annualized net returns, and cash rent flexed on yield scenario has the highest annualized net returns based on the model assumptions.

The third chapter incorporates a safety-first constraint into the dynamic programming model developed in Chapter 2 to determine the optimal crop rotation for a peanut and cotton producer in Alabama under alternative land tenure arrangements assuming a producer can choose to leave land fallow. Adopting a peanut/cotton crop rotation with the option of fallowing with consideration given to the type of land tenure arrangement may be an appropriate risk management option for producers.

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Chapter 1

Evaluating cotton production profitability when considering cotton quality as an output

Abstract

The impact of row spacing, tillage, and seed traits on cotton profitability in Alabama was evaluated, and an application of a single equation and a multi-equation approach were used to estimate profits. Overall, estimating a single equation profit function and constructing profit from multi-equation response functions produced similar results. Results showed that the production option providing maximum profits was highly dependent on rainfall amounts received during the growing season. Non-transgenic seed planted with standard and narrow spacing utilizing both conservation and conventional tillage were in the top five most profitable production options regardless of rainfall amount and estimation method. Agricultural producers are faced with numerous production options and decisions must be based on what works best for their operation and expected weather conditions.

1.1 Introduction

In 1970, cotton (*Gossypium hirsutum* L.) production encompassed approximately 565 thousand acres in Alabama with an average lint cotton yield of 453 lbs ac^{-1}. Forty-one years later, the environment for cotton production looks very different. For 2011, 460 thousand acres of upland cotton were planted in Alabama (up ~35% from 2010), 105 thousand less acres than planted in 1970; however, cotton production in Alabama was approximately 35% higher in 2011 than in 1970. The real price of cotton in 1970[1] was higher than the price of cotton in 2011 by approximately 8% in Alabama and across the United States (U.S.). In 2011, average yields in Alabama increased to 742 lbs ac^{-1} but were highly variable due to different production decisions and rainfall patterns.

Agricultural producers are faced with a litany of conditions that influence their profitability, from climate and weather variability to weed, insect, and disease pressure. Certain conditions can be addressed with technology and production methods (e.g., seed genetics and pesticide regimens); however, adoption of new production methods can produce higher or lower yields, as well as differences in cotton quality. Agricultural research is necessary to assist producers in adoption of appropriate new technology and production methods for their operations. If a given production system does not maximize profits, few agricultural producers will adopt such systems.

The research presented in this article adds to the existing literature through the application of a single equation and a multi-equation approach for estimating the profitability of cotton production. Furthermore, this research investigates the impact of row spacing, tillage, and seed traits on profitability. The hypothesis of this article is that estimating a single equation profit function provides results similar to those produced by estimating multi-equation response functions for seed cotton yield and quality attributes, and calculating profit from the response functions. However, multi-equation response functions guide research and provide producers more insight into technology. The two main objectives of this article are to: (1) assess the influence of herbicide traits, tillage,

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[1] Price data were deflated to 2011 constant dollars using the implicit price deflator for gross domestic product (U.S. Department of Commerce, 2013).

and row spacing on profitability of cotton using experimental data from Alabama, considering quality as an output; and (2) determine if there is a meaningful difference between a single equation or a multi-equation approach for estimating profit.

1.2 Review of Previous Research

Narrow row cotton production combined with a conservation tillage system can potentially improve productivity and increase profits. When narrow row cotton was first introduced, one of the main barriers to adoption was the ability to control weeds within the growing season with only soil applied herbicide options. The advent of various transgenic cultivars with herbicide-resistant traits provides weed control opportunities for viable narrow row cotton in conservation tillage systems. Across the U.S., approximately 90% of cotton acres were planted to transgenic cotton varieties, including varieties with insect-resistant, herbicide-tolerant, and stacked traits in 2011 (Fernandez-Cornejo et al., 2014). Scientists in agronomy, weed science, and economics have published research results on the impact of adopting these production methods across yields, quality attributes, and net returns (Askew et al., 2002; Balkcom et al., 2010; Jost and Cothren, 2000; Jost et al., 2008; Larson, Roberts, and Gwathmey, 2007; Larson et al., 2009). Table 1.1 summarizes economic and agronomic literature, including a comparison of the data, as well as estimation techniques.

Table 1.1. Summary of the literature

Source	Location	Study Years	Data and Technique
Askew et al. (2002)	North Carolina	1997 – 1998	Herbicide weed control was not affected by tillage; however, tillage did increase yields over no-tillage. Estimate a profit function.
Balkcom et al. (2010)	Alabama	2004 – 2006	Cotton plant growth and yield marginally affected by row spacing, tillage system, and herbicide technology. Profitability not considered.
Belasco, Schroeder, and Goodwin (2010)	Kansas and Nebraska	unknown	Quality and yield risk influences variability of expected profit.
Boquet, Hutchinson, and Breitenbeck (2004)	Louisiana	1991-2001	Conservation tillage and cover crops increases farm productivity through higher cotton yields, as well as quality attributes. Profitability not considered.
Britt, Ramirez, and Carpio (2002)	Texas	1997-1999	Quality considerations could increase profitability of cotton and reduce risk related to climate. Estimates yield and quality response functions and calculates a profit equation.
Jost and Cothren (2000)	Texas	1997-1998	The influence of row spacing on cotton yields is dependent on rainfall. Fiber length is influenced by row spacing. Profitability not considered.
Jost et al. (2008)	Georgia	2001-2004	Overall, transgenic technology systems did not provide greater returns than nontransgenic systems. Profitability related to yield, not technology. Estimates a profit function.
Larson et al. (2009)	Tennessee	2003-2005	Row spacing had little effect on differences in fiber quality of cotton. Skip-row planting provided higher net returns relative to sold row configurations. Estimates a profit function.

Larson, Roberts, and Gwathmey (2007)	Tennessee	1997-2000	Using ultra-narrow-row cotton increases yield by a small amount due to an increase in the number of plants. Technology fees provide an incentive for producers not to use ultra-narrow-row cotton.
Larson et al. (2001)	Tennessee	1981-1997	The variability of cotton yields, when grown after a cover crop, depends on the type of cover crop, as well as the amount of nitrogen applied. Utilizes a Just-Pope econometric model.
Lichtenberg and Zilberman (1986)	Not Applicable		Develops an econometric model to include damage control agents, and demonstrates why it is important to use the correct specification for damage control processes when estimating a production function.
Saha, Shumway, and Havenner (1997)	Kansas	1973-1990	Damage control inputs should be modeled differently from production inputs. Misspecification of a production function can lead to overestimation of the marginal physical productivity of the inputs, particularly damage control inputs.
Smith, McKenzie, and Grant (2003)	Canada	1997-2000	The amount of nitrogen applied to wheat increases yield variability but decreases price variability when there are protein premiums or discounts. Estimate a profit function.
Zago (2009)	Italy	1994-1996	Found a trade-off between yield and quality in wine grapes using a method that allow for more than one quality component.
Zhengfei et al. (2005)	Netherlands	1990-1999	Find lower pesticide productivity than in previous publications. Using an asymmetric specification, they find conventional farmers use pesticide optimally. They use a damage control specification that the productivity of pesticides to be negative. Different technologies are used by organic versus conventional farmers.
Zhengfei et al. (2006)	Netherlands	1990-1999	Develop a model to incorporate agronomic principles into economic production functions. Land used for potato production is productive; however, labor and capital are used in excess.

Balkcom et al. (2010) found that cotton plant growth and yield are marginally affected by row spacing, tillage system, and herbicide trait. They concluded that treatment effects on lint yield are influenced by growing season, and that narrow row cotton could be beneficial for some producers depending on the profitability of the system. Boquet, Hutchinson, and Breitenbeck (2004) concluded that conservation tillage and cover crops increases farm productivity through higher cotton yields. They also found that tillage, cover crops, and nitrogen rates had a significant influence on cotton quality attributes; however, they concluded that the differences were not of economically significant concern. Jost and Cothern (2000) noted yield differences for cotton planted in standard row and ultra-narrow row spacings. They found that yields were higher for narrow row spacing in a dry growing season and the same across treatments in a wet growing season, with fiber length influenced by row spacing.

Economists have investigated profitability of cotton production systems. Larson et al. (2001) evaluated how different winter cover crops and tillage decisions affect cotton lint yield, nitrogen fertilization rates, production costs, and net revenues. They conclude that, while profits were lower for cotton following hairy vetch (*Vicia villosa* L.), the results are strongly influenced by the cost of cover crop seed and other production costs. Jost et al. (2008) compare the economic effects of transgenic and non-transgenic cotton production systems using experimental data from Georgia. Their main conclusion was that profitability was more closely tied to yields than with transgenic technologies.

In general, agronomic and economic researchers take different approaches to estimating production (response) functions. In the past 25 years, a number of articles have been published demonstrating the alignment of production functions more closely with agronomic principles; commonly referred to as an asymmetric production function (Lichtenberg and Zilberman, 1986; Saha et al., 1997; Zhengfei et al., 2005; Zhengfei et al., 2006). Zhengfei et al. (2005) stated that, in the common specification of the production function, there is no distinction made between production inputs (e.g., labor) and damage-abating inputs (e.g., pesticides). On the other hand, production functions aligned more closely with agriculture are asymmetric, and a different functional form is specified for production and damage-abatement functions. Although this appealing approach was considered, data limitations made it necessary to take a different approach in this research.

Wine grapes (*Vitis vinifera* L.*)*, beef, cotton, and wheat (*Triticum aestivum* L.) are a few of the many agricultural commodities with price premiums or discounts based on quality. There have been several studies addressing quality attributes in production functions and more specifically, incorporating quality risk into production functions. Zago (2009) developed a quality indicator based on the directional distance function for wine grapes and analyzed trade-offs between quantity and quality using experimental data from Italy. Belasco, Schroeder, and Goodwin (2010) evaluated the quality risk of cattle carcasses using data from feedlots in Kansas and Nebraska. Their research provides a framework for investigating factors influencing quality, price, and yield risk related to cattle-feeding. They conclude that trade-offs exist between yield and quality grades.

The influence of production decisions on quality and yield has a direct impact on profitability. Britt, Ramirez, and Carpio (2002) and Smith, McKenzie, and Grant (2003) described the relationship between production decisions, crop yield and quality, and profitability in two different ways. Britt, Ramirez, and Carpio (2002) examined profit variability and changes in profit with a decline in uncertainty related to weather for Texas cotton production. They estimated response functions for six outputs: cotton lint yield, cottonseed yield, micronaire, strength, staple, and turnout. Outputs were functions of rainfall, heat units, irrigation water, and fertilizer use, while premiums or discounts were a function of quality. Response equations were linear specifications for all variables except for irrigation water and fertilizer use, which were specified as third-degree polynomials. Their overall results were that, if a producer chose a profit maximizing set of inputs, while considering quality, and had access to perfect climate information, they would increase their profitability and minimize their risk. They identified the availability of only three years of experimental data, imperfections due to random errors, and differences between an experimental site and a working farm as several weaknesses in their model and data.

Smith, McKenzie, and Grant (2003) investigated the optimal amount of fertilizer use under risk when both Canadian Western Red Spring wheat yield and price were a function of production inputs. Wheat yield, protein, price and revenue were modeled as dependent variables. The authors estimated dependent variables and costs as functions of nitrogen fertilizer and a vector of other inputs. Risk was incorporated through the use of the Just-Pope production function (Just and Pope, 1979). The mean and variance for all four dependent variables were estimated using a translog functional form. Their main conclusion was that applying higher rates of nitrogen fertilizer on wheat will increase wheat protein, providing producers with a higher price for their product.

1.3 Data and Methods

1.3.1 Study Area and Experimental Design

Cotton yield and quality data were from an experiment at E.V. Smith Research Center (EVS) near Shorter, Alabama conducted by scientists from the United States Department of Agriculture, Agricultural Research Service (USDA-ARS), National Soil Dynamics Laboratory (NSDL) in Auburn, Alabama. The experiment was initiated in the fall of 2003 and terminated after cotton harvest in 2006. The experimental design was a split-split plot treatment in a randomized complete block design, replicated four times. Main plots were two row spacing options: 15 in (NS) and 40 in (SS). Subplots were three herbicide traits: conventional (CV), glyphosate-tolerant (GL), and glufosinate-tolerant (GU). Sub-subplots were two tillage systems: conventional (CVT) and conservation tillage (CST).

Combined together, there were 12 production options (i.e., Option 1, Option 2, etc.) that were compared in this study (Table 1.2). Three herbicide traits were chosen from the same parent line to minimize genetic differences. This allowed for the majority of cultivar difference to be restricted to the herbicide trait. Additional information on materials and methods employed in this experiment are found in Balkcom et al. (2010).

Table 1.2. Production options and associated production costs

Production Option	Spacing [S]	Tillage [T]	Seed Trait	Production Costs (US$ ac^{-1})
1	Standard [SS]	Conventional [CVT]	Non-transgenic [CV]	$75.23
2	[SS]	[CVT]	Glyphosate-tolerant [GL]	$144.21
3	[SS]	[CVT]	Glufosinate-tolerant [GU]	$146.53
4	[SS]	Conservation [CST]	[CV]	$64.77
5	[SS]	[CST]	[GL]	$125.00
6	[SS]	[CST]	[GU]	$127.33
7	Narrow [NS]	[CVT]	[CV]	$91.66
8	[NS]	[CVT]	[GL]	$164.26
9	[NS]	[CVT]	[GU]	$180.08
10	[NS]	[CST]	[CV]	$81.20
11	[NS]	[CST]	[GL]	$145.06
12	[NS]	[CST]	[GU]	$160.87

The focus of this study was on differences between treatments. For example, different seeding rates and planting methods were used for narrow row spacing treatments versus standard row spacing treatments, while the amount of starter fertilizer was equal for all plots and treatments. Subsamples of seed cotton were ginned to determine ginning percentage (turnout). Seed cotton is the total yield and includes lint, seed, and trash. Cotton lint yield is the seed cotton yield multiplied by the ginning percentage, and cottonseed yield is the cotton lint yield multiplied by 1.6. Samples were also evaluated to determine lint quality attributes: color, leaf, staple, strength, micronaire, and uniformity. Following Britt, Ramirez, and Carpio (2002), color and leaf were not included in this article; however, unlike Britt, Ramirez, and Carpio (2002), a response function was estimated for uniformity. Rainfall amounts were collected daily at EVS, and annual rainfall amounts were calculated from the date of planting to the date of harvest. Plots were planted on May 25, 2004, May 17, 2005, and May 17, 2006, and were harvested on October 4, 2004, October 11, 2005, and October 11, 2006. Rainfall totals for 2004, 2005, and 2006 were 19.61 inches, 17.42 inches, and 12.40 inches, respectively. The most favorable growing conditions (based on rainfall during the growing season) occurred in 2005, as compared to 2004 and 2006.

Experimental data does provide challenges for economic analysis, since the data only included 144 observations over three years. Variability in production methods and efficiency that exist at the farm level are minimized in experimental data, and three years of data are inadequate to definitely address risk. Plots are managed as a controlled experiment with changes occurring on a specific schedule, given exact rates. Summary statistics and definitions for the variables are presented in Table 1.3. Profit per acre ranged from -155.08 US$ ac^{-1} to 988.69 US$ ac^{-1}, with an average of 399.44 US$ ac^{-1}. Across all production options, average lint yield was 1012.89 lbs ac^{-1}, with a minimum of 450.09 lbs ac^{-1} and a maximum of 1839.60 lbs ac^{-1}.

Table 1.3. Summary statistics and variable names

Variable	N	Mean	Std Dev	Minimum	Maximum
Profit (US$ ac^{-1}) [p]	144	399.44	243.34	-155.08	988.69
Seed yield (lb ac^{-1}) [y]	144	2464.64	811.92	1072.55	4515.39
Ginning percentage [g]	144	41.32	1.67	37.86	46.56
Cotton Lint (lb ac^{-1}) [l]	144	1012.89	321.13	450.09	1839.60
Staple [sp]	144	36.34	1.42	31.00	39.00
Micronaire [m]	144	40.50	6.62	29.00	57.00
Uniformity [u]	144	82.46	1.82	78.10	86.00
Strength [sr]	144	33.80	2.49	24.80	39.00
Rainfall (inches growing season^{-1}) [r]	144	16.42	3.01	12.40	19.61
Tillage (0 if conventional tillage, 1 if conservation tillage) [t]					
Spacing (0 if standard spacing, 1 if narrow spacing) [s]					
Conventional seed (1 if conventional, 0 otherwise) [cv]					
Glyphosate-tolerant seed (1 if glyphosate-tolerant, 0 otherwise) [gl]					
Glufosinate-tolerant seed (1 if glufosinate-tolerant, 0 otherwise) [gu]					

Yields from experiments tend to be higher than actual on-farm yields. For 2004, 2005, and 2006, the average state cotton lint yields for Alabama were 724 lbs ac^{-1}, 747 lbs ac^{-1}, and 579 lbs ac^{-1}. This average includes yields for both irrigated and non-irrigated cotton production from across the state of Alabama. Seed cotton yields at a 25% and 50% reduction were considered as part of a sensitivity analysis.

1.3.2 Production inputs and prices

Variable production costs for each production option were estimated using production practices and inputs for each treatment (Table 1.2). Production costs were adapted from two primary sources: the Mississippi State Budget Generator v.6.0 (Laughlin and Spurlock, 2003) and the USDA-National Agricultural Statistics Service (USDA-NASS). All variable production costs were from the 2010 crop year. Fixed costs were not included in the analysis, and variable production costs were the inputs that differed between production options. Specifically, production costs that differed were seed cost and associated technology fees, machinery and labor costs associated with tillage and planting, and costs of pesticides and application. Ginning/hauling costs are a function of cotton lint yield and were assumed to be 0.09 US$ lb^{-1} of cotton lint. Remaining input costs, such as cover crop establishment and termination, fertilizer rates and application, and cotton harvest, were held constant across production options.

Conventional tillage and GU seed planted in narrow rows (Option 11) was the production option with the highest production cost per acre, not including ginning cost. While GL seed had the highest seed and technology cost, more expensive herbicides are associated with production using GU seed. Cotton lint harvested from the experimental data plots was not sold at market; therefore, an actual market price was not available for the samples. The 2010 national cotton loan rate of 0.52 US$ lb^{-1} and the 2010 cotton loan premiums and discounts are included in the calculation of total revenue[2]. The USDA-Agricultural Marketing Service (USDA-AMS) provides daily spot cotton quotations and premiums and discounts by region. The spot cotton price is based on color 41, leaf 4, staple 34, micronaire 35-36 and 43-49, and strength 26.5-28.4. For the southeast region, the season average spot cotton price for August 2009 to July 2010 was 70.13 cents $pound^{-1}$ (USDA, 2010). Quality variability impacts the price an agricultural producer receives for their product. For example, if the quality of a cotton sample was color 41, leaf 2, staple 34, micronaire 35, and strength 26.5, the spot cotton price was 67.38 cents $pound^{-1}$, based on premium and discount schedules for 2009/2010.

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[2] The national loan rate for cotton was from the Food, Conservation and Energy Act of 2008.

The cotton loan rate and premiums and discounts were used in determining the dollar amount available to producers from USDA through nonrecourse marketing loans. In this analysis, premiums and discounts for staple, micronaire, strength, and uniformity were included in the total revenue calculation. Discounts and premiums associated with color and leaf were not included due to data limitations. This is consistent with existing literature (Britt, Ramirez, and Carpio, 2002). The price received for cottonseed was 132 US\$ ton^{-1} representing the average 2010 price received by producers in Alabama (USDA, 2013).

1.4 Model Specification

1.4.1 Overview

The basic definition of economic profit is the difference between total revenue and total cost. It was assumed that producers make production decisions that maximize their profits. In the simplest form, profit (π) is:

$$\pi = py - wx \tag{1.1}$$

where p is the price of the output, y is the output, w is the cost of the input and x is the quantity of input. Although cotton has traditionally had two outputs (cotton lint and cottonseed), it is feasible to consider cotton in the context of multi-product production, where quality attributes are defined as outputs. Production decisions influence the level of quality and quality influences total revenues received by producers. For purposes of this study, factors of production were defined as non-allocable, since it was not possible to distinguish between inputs utilized to produce cotton lint, quality, or cottonseed.

Profits, when cotton lint, cottonseed, and quality attributes were considered as outputs and inputs were non-allocable, were calculated as:

$$\pi = p_l y_l + p_q y_l + p_c y_c - wx. \tag{1.2}$$

On the revenue side, p_l is price (US\$ lb^{-1}) for cotton lint; $p_q$is the premium or discount price (US\$ lb^{-1}) as a function of cotton quality attributes; p_c is the price (US\$ ton^{-1}) of cottonseed; y_l is the cotton lint yield (lbs ac^{-1}) which is the seed cotton yield multiplied by the ginning percentage; and y_c is the cottonseed yield (ton ac^{-1}). On the cost side, x is a vector of inputs, and w is a vector of input costs, which included variable production costs plus variable costs that are a function of cotton lint yield, such as ginning costs.

To estimate profits, two different approaches were considered in this study. First, a single equation estimated profit as a function of rainfall and production methods examined as part of the experimental design (Method 1). Estimated profits were then compared across the 12 production options. The second approach was to calculate profit by estimating multi-equations for seed cotton yield, ginning percentage, and quality attributes (Method 2). Calculated profits were again compared across the 12 production options.

1.4.2 Estimating a Single Equation Profit Function

The first step was to calculate profit from actual data for each observation, accounting for discount and premiums associated with quality attributes. Profit was calculated for each observation using experimental data employing Equation 1.2. In the second step, using calculated profits from the first step, a single equation profit function was estimated, where profit was a function of rainfall and production methods. Ordinary least squares estimation (OLS) was utilized to estimate the profit function.

The function was specified with an intercept, ten independent variables, including a quadratic and four interaction terms, and an additive error term:

$$\pi = \alpha_0 + \alpha_1 r + \alpha_2 r^2 + \alpha_3 t + \alpha_4 s + \alpha_5 gl + \alpha_6 gu + \alpha_7 rt + \alpha_8 rs + \alpha_9 rgl + \alpha_{10} rgu + \varepsilon \tag{1.3}$$

In Equation 1.3, π is profit (US\$ ac^{-1}), as defined in Equation 1.2; *r* is rainfall (inches) received from the planting date to the harvest date; r^2 is a second-degree polynomial with respect to rainfall, further referred to as the quadratic rainfall variable; *t* is the dummy variable for type of tillage where 0 is CVT and 1 is CST; *s* is the dummy variable for type of row spacing where 0 is SS and 1 is NS; *gl* is the dummy variable for GL seed where 1 is GL seed and 0 is other seed types; *gu* is GU seed where 1 is GU seed and 0 is other seed types; cv is the dummy variable for CV seed where 1 is CV seed and 0 is other seed types; parameter estimates were represented by α; and ε is the error term. The base production option was CVT, SS and CV seed (Option 1). In Method 1, interactions were included for rainfall, which is representative of year, and each of the production variables. Including interaction terms allows for different profit levels for tillage, spacing, and cultivar.

1.4.3 Calculating Profit from Yield and Quality Response Functions

Response functions for seed cotton yield, ginning percentage, and the four quality attributes (staple, micronaire, strength, and uniformity) were estimated using OLS.[3] Each function was specified as the following:

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[3] An alternative approach was to use iterated seemingly unrelated regression (ITSUR), where estimates of the cross-equation covariance matrix were computed from the seemingly unrelated regression (SUR) residuals in the SUR estimation. However, when each equation had the same independent variables, OLS provided identical results (Greene, 2000).

$$y_k = \alpha_{0k} + \alpha_{1k}r + \alpha_{2k}r^2 + \alpha_{3k}t + \alpha_{4k}s + \alpha_{5k}gl + \alpha_{6k}gu + \alpha_{7k}rt + \alpha_{8k}rs + \alpha_{9k}rgl + \alpha_{10k}rgu + \varepsilon_k. \quad (1.4)$$

In Equation 1.4, y_k is output for seed cotton yield, ginning percentage, staple, micronaire, strength, or uniformity, and the remaining variables and parameters are identical to Equation 1.3. The profit function used to construct profit from multi-equation response functions using predicted values for seed cotton yield and quality response was:

$$\pi = \sum p_k y_k - wx, \quad (1.5)$$

where π is per acre profit, p_k is the price of the output, y_k is the output, *w* is the cost of the input(s) and *x* is the quantity of input(s).

1.5 Results and Discussion

1.5.1 Results for Method 1

Regression results for the single equation profit function are presented in Table 1.4. Profit was estimated with and without the quadratic rainfall variable (Model 1 and Model 2, respectively). Based on the *F* statistic, the hypothesis that the quadratic rainfall variable had no effect on profit was rejected at the 1% significance level (*F* statistic = 181). Based on White's general test for heteroskedasticity, the null hypothesis that there was no heteroskedasticity was rejected at the 5% significance level for Model 1 and Model 2. Outliers can cause heteroskedasticity, and there were eight observations for profit that were more than two standard deviations from the mean. When Models 1 and 2 were estimated without the outliers, the null hypothesis of homoskedasticity was not rejected. Since the data were obtained in a carefully controlled and monitored experiment, it seemed inappropriate to remove statistical outliers; therefore, outliers were not removed from the data. To account for heteroskedasticity, both models were estimated using the heteroskedasticity-consistent covariance matrix estimation method (HCCME).

Table 1.4. Regression estimates for Method 1 and Method 2

Independent Variable	Method 1		Method 2 (Dependent Variables in Log Form)					
	Model 1	Model 2	Seed Yield	Ginning Percentage	Staple	Micronaire	Strength	Uniformity
Intercept	-7373.24***[1]	-361.80***	-4.189***	4.166***	3.703***	5.652***	4.322***	3.282***
	(539.70)[2]	(131.70)	(0.6293)	(0.096)	(0.1028)	(0.3016)	(0.0171)	(0.0631)
Rainfall [r]	973.14***	52.92***	1.463***	-0.050***	-0.023*	-0.213***	0.006***	0.016***
	(68.86)	(8.62)	(0.0791)	(0.0117)	(0.0124)	(0.0390)	(0.0010)	(0.0034)
[r] * [r]	-29.07***		-0.043***	0.0014***	0.001**	0.0056***		
	(2.16)		(0.0024)	(0.0004)	(0.0004)	(0.0012)		
Tillage [t]	359.96***	359.96**	0.572***	-0.021	0.087**	0.120*	0.034**	0.099*
	(127.1)	(145.30)	(0.1509)	(0.0288)	(0.0344)	(0.0687)	(0.0136)	(0.0594)
Spacing [s]	-95.09	-95.09	-0.017	0.003	-0.0485	-0.029	-0.013	-0.017
	(127.1)	(145.30)	(0.1509)	(0.0288)	(0.0344)	(0.0687)	(0.0136)	(0.0594)
Glyphosate-tolerant seed [gl]	571.64***	571.64***	0.686***	0.073**	-0.073	0.175**	-0.030*	-0.204**
	(155.6)	(181.2)	(0.1716)	(0.0337)	(0.0486)	(0.0825)	(0.0173)	(0.0794)
Glufosinate-tolerant seed [gu]	-128.79	-128.79	-0.002	0.028	-0.017	-0.006	-0.024	0.009
	(155.6)	(165.5)	(0.1976)	(0.0364)	(0.0309)	(0.0773)	(0.0175)	(0.0594)
[r] * [t]	-23.50***	-23.50**	-0.036***	0.0004	-0.004**	-0.008*	-0.002**	-0.005
	(7.61)	(9.38)	(0.009)	(0.0016)	(0.0019)	(0.0041)	(0.0008)	(0.0033)
[r] * [s]	5.14	5.14	0.003	0.00005	0.003	0.002	0.001	0.001
	(7.61)	(9.38)	(0.009)	(0.0016)	(0.0019)	(0.0041)	(0.0008)	(0.0033)
[r] * [gl]	-44.66***	-44.66***	-0.038***	-0.004*	0.004	-0.015***	0.001	0.008*
	(9.32)	(11.91)	(0.010)	(0.0019)	(0.0027)	(0.0049)	(0.0010)	(0.0043)
[r] * [gu]	1.37	1.37	-0.002	-0.003	0.0004	0.002	0.001	-0.002
	(9.32)	(10.60)	(0.012)	(0.0021)	(0.0017)	(0.0047)	(0.0010)	(0.0033)
N	144		144					

R^2	0.7052	0.3033	0.8070	0.6280	0.5372	0.8087	0.7309	0.6016
Adjusted R^2	0.6831	0.2565	0.7925	0.6000	0.5024	0.7943	0.7128	0.5748
F statistics (critical value)	181.32							

[1] ***, **, * represents statistical significance at the 1%, 5%, and 10% levels, respectively

[2] Numbers in parentheses are standard errors.

The following discussion focuses solely on results from Model 1, a single equation profit function with a quadratic rainfall variable. Coefficients on rainfall and the quadratic rainfall variable were positive and negative, respectively, as expected, and highly significant; however, to interpret the effect of rainfall, consideration was given to the interaction terms. For Option 1 (the base scenario), profits were maximized at a rainfall level of 16.73 inches, where the first derivative was zero. An additional inch of rainfall (i.e., from 16.73 inches to 17.73 inches) decreased profits decreased by 29.07 US\$ ac^{-1}.

When considering tillage, a move from conventional tillage to conservation tillage increased profits; however, the interaction between rainfall and tillage was significant so consideration was given to the interaction term. Assuming 16.42 inches of rainfall, the use of conservation tillage as compared to conventional tillage decreased profit by 23.50 US\$ ac^{-1}, all things equal. The interaction between rainfall and tillage was negative and significant. Profits were higher for conservation tillage with rainfall amounts less than 15.32 inches, after which increases in rainfall decreased profits relative to conventional tillage. For Option 4, an increase from 16.73 inches to 17.73 inches decreased profits by 52.11 US\$ ac^{-1}.

The parameter for GL seed was also negative and highly significant, as well as the interaction with rainfall. Assuming average rainfall, the adoption of Option 2 decreased profits by 161.61 US\$ ac^{-1}, as compared to Option 1. Row spacing and GU seed were not statistically significant ($P \leq 0.10$) and were not discussed; however, based on the *F*-statistic, both variables and their interactions with rainfall were significant to the model.

1.5.2 Results for Method 2

Regression results for the multi-equation response functions for seed cotton yield, ginning percentage, and quality attributes are presented in Table 1.4. Based on results from the *F* test, a quadratic rainfall variable was included in the seed cotton yield, ginning percentage, staple and micronaire equations, and was excluded from the strength and uniformity equations. Since dependent variables were transformed using the natural log, predicting output (y_k) by taking the exponential of log (y_k) underestimates the expected value of y_k. The predicted value of y_k was estimated following steps outlined by Wooldridge (2000).

As in Method 1, row spacing, GU seed, and their interactions with rainfall were not statistically significant for any of the response functions ($P \leq 0.10$); however, based on the F-statistic, they were significant to each of the response functions. For all six response functions, rainfall was significant at 1% for seed cotton yield, ginning percentage, micronaire, strength, and uniformity, and at the 10% significance level for staple. The quadratic rainfall variable was significant at the 1% level for seed yield, ginning percentage, and micronaire, and at the 5% significance level for staple. Aside from seed cotton yield, the coefficient for rainfall was negative and the coefficient for the quadratic rainfall variable was positive implying a minimum rainfall amount. The magnitude of the coefficients for the quadratic rainfall variable for ginning percentage, staple, and micronaire were small, and meaningful conclusions were limited by only three years of rainfall data.

An evaluation of the results for Option 1 showed that the first inch of rainfall increased seed cotton yield by approximately 146%, while the second inch increased seed cotton yield by 4.3% less than the first inch. For seed cotton yield, ginning percentage, staple, and micronaire, the turning point was 17.01 inches, 17.86 inches, 11.5 inches, and 19.02 inches, respectively. It is important to note that for ginning percentage and micronaire, maximum rainfall amounts were above the average rainfall, and for staple, the maximum rainfall amount was below the minimum rainfall for the experiment.

There are limitations to using rainfall as an independent variable. There were only three rainfall observations, and all three data points were below the average for growing seasons (May 17 to October 11) between 1950 and 2012 of 20.80 inches.[4] Therefore, the results only apply to years with similar rainfall amounts. Additional research is needed to determine the optimal amount of rainfall data needed to make reliable predictions. For example, it may be beneficial in future research to use total rainfall received during the blooming stage (a critical growth stage) as an explanatory variable.

Moving from conventional tillage to conservation tillage had a positive effect on seed cotton yield and quality attributes; however, the interaction with rainfall had a negative effect on seed cotton yield, staple, micronaire, and strength. The use of conservation tillage provided higher seed cotton yields at lower rainfall levels, while the use of conventional tillage provided higher seed cotton yields at higher rainfall levels.

For micronaire, conservation tillage produced higher micronaire levels in drier years and conventional tillage produced higher levels in wetter years. Micronaire is related to maturity of the cotton plant. In experimental plots, all plots were harvested at the same time regardless of treatment. It was possible that cotton planted using conservation tillage matured slower than cotton planted using conventional tillage. This

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[4] Rainfall data was procured from AWIS Weather Service.

may have negatively impacted micronaire of cotton planted using conservation tillage, thereby increasing discount points per pound. Further research is needed to determine whether such bias is present in experimental data.

At average rainfall from 2004 to 2006, the adoption of conservation tillage, as opposed to conventional tillage, decreased seed cotton yield by 1.37% and micronaire by 0.57%. Staple and strength increased by 1.68% and 2.15%, respectively. As micronaire decreased below 3.5, the level of discount applied to the cotton price increased, so a move from a micronaire reading of 3.3 to 2.8 increased the discount from -180 points pound^{-1} to -645 points pound^{-1}. The same was true for strength, where the lower the fiber strength the higher the discount. Profits were lower under conservation tillage given rainfall of 16.42 inches; however, as rainfall decreased, profitability of conservation tillage increased.

There is a wide range of prices for seed trait, with the lowest being CV seed; however, many producers prefer using a GL or GU seed instead of CV seed. Alone, a move to GL seed from CV seed increased seed cotton yield; however, once the interaction with rainfall was factored in, there was a reduction in seed cotton yield per inch of rain. Assuming average rainfall from 2004 to 2006, the use of GL seed instead of CV seed increased seed cotton yields by 6.40%. There was a similar effect on ginning percentage (1.57% increase) and micronaire (7.16% reduction), both of which may have negatively impacted profit. Uniformity decreased by 1.11% with a move from CV to GL seed, which had a negative impact on profit due to a potential discount on the price received by producers. As expected, the growing conditions, particularly rainfall in this study, heavily influenced yield and quality driving profitability of the production options.

1.5.3 Maximizing Profits using Method 1 and Method 2

Table 1.5 displays average profit for all 12 production options for Method 1 and Method 2. Profit (π) is the actual profit as calculated from the data. For both Method 1 and Method 2, $phat$ is the predicted mean, $phat_{min}$ is the predicted mean using the minimum rainfall in the sample, and $phat_{max}$ is the predicted mean using the maximum rainfall in the sample. Regardless of the method, Options 1 and 7 provided the highest profits, followed by Options 4 and 10. Assuming minimum rainfall amounts and using Method 1, the four most profitable production options were: Option 5 > Option 4 > Option 11 > Option 10. Assuming minimum rainfall amounts and using Method 2, the results were similar to Method 1: Option 5 > Option 11 > Option 4 > Option 10. The most profitable production options assuming maximum rainfall were similar to the overall results regardless of method.

Table 1.5. Average Profits for Production Options (US\$ ac^{-1})

Production		Method 1			Method 2		
Options	π	$phat$	$phat_{min}$	$phat_{max}$	$phat$	$phat_{min}$	$phat_{max}$
1	$477.40	**$507.02**	$224.20	$531.83	$546.63	$288.55	$560.99
2	$357.63	$345.41	$242.01	$227.63	$333.90	$284.93	$271.36
3	$399.94	$400.79	$112.44	$429.98	$437.96	$203.73	$443.76
4	$492.52	$481.19	$292.76	$430.97	$522.74	$342.43	$474.03
5	$337.95	$319.58	**$310.58**	$126.77	$312.74	**$377.78**	$101.60
6	$363.50	$374.95	$181.01	$329.12	$380.17	$116.17	$384.86
7	**$548.13**	$496.26	$192.80	**$537.46**	**$551.25**	$279.61	**$570.61**
8	$302.82	$334.65	$210.61	$233.26	$308.74	$212.39	$268.33
9	$388.23	$390.02	$81.04	$435.61	$424.14	$177.39	$434.38
10	$436.84	$470.42	$261.36	$436.60	$525.78	$334.39	$479.67
11	$310.05	$308.81	$279.18	$132.40	$296.32	$368.08	$90.82
12	$378.28	$364.19	$149.61	$334.75	$414.60	$239.27	$372.29

Note: π = profit per acre; $Phat$ = the estimated profit (Method 1) and the constructed profit (Method 2); $phat_{min}$ = the profit using the minimum rainfall; $phat_{max}$ = the average profit using the maximum rainfall. Numbers in bold are the most profitable production option.

Production options with narrow row spacing were distributed throughout the ranking of production options. Using Method 1, production options with narrow row spacing had lower profits than equivalent standard row spacing production options (i.e., Option 1 > Option 7). This was not true for Method 2, where production options with standard row spacing did not consistently outperform production options with narrow row spacing (i.e., Option 1 < Option 7). The assumption in this study was that producers owned the machinery needed to adopt narrow row spacing. If producers purchased new machinery, production costs associated with narrow row spacing would increase, further decreasing potential profits as compared to production options with standard row spacing. Production options with CV seed (across spacing and tillage) had higher average profits than GL and GU seed, and production options with GU seed had higher average profits than with GL seed. This was due primarily to higher seed cost, particularly technology fees of GL and GU seed, as well as more expensive herbicide applications.

Profitability of conservation tillage as compared to conventional tillage in this experiment depends heavily on rainfall received during the growing season. Under minimum rainfall, the four most profitable options all included conservation tillage, and under maximum rainfall, two of the four most profitable options included conservation tillage. It is important to note that Option 10 was in the top four most profitable options regardless of rainfall amount and estimation method. This was also true for Option 4 except under maximum rainfall, where it was the fifth most profitable option by 4.64 US\$ ac^{-1}. Options 4 and 10 consistently performed well regardless of rainfall amount.

Predicted profits of Method 1 were compared to predicted profits of Method 2. As shown in the fourth column of Table 1.6, the difference between the two methods was dependent on the production option. In eight out of 12 production options, a higher predicted profit was estimated by Method 2. Production Options 5 and 6 had the most similar predicted profits between the two methods. The two options with the greatest difference between Methods 1 and 2 were Options 7 and 10. Overall, it appears that Method 2 overestimated profit, as compared to Method 1. Method 1 provided a more conservative estimate of predicted profits. This may be due to the greater influence of discounts and premiums on the calculated profit in Method 2. Traditional statistical tests were not used to compare the two Methods as model selection tests are designed to compare a null model with an alternative; however, in this case, the two methods have different dependent variables and due to the nature of agronomic experiments, the sample size was small (Judge et al., 1985).

Table 1.6. Difference between methods 1 and 2 for the overall mean and by production option (US\$ ac^{-1})

Production Options	*phat (Method 1)*	*phat2 (Method 2)*	*phat (Method 1) – phat2 (Method 2)*
1	\$507.02	\$546.63	-\$39.60
2	\$345.41	\$333.90	\$11.51
3	\$400.79	\$437.96	-\$37.17
4	\$481.19	\$522.74	-\$41.55
5	\$319.58	\$312.74	\$6.84
6	\$374.95	\$380.17	-\$5.21
7	\$496.26	\$551.25	-\$54.99
8	\$334.65	\$308.74	\$25.90
9	\$390.02	\$424.14	-\$34.12
10	\$470.42	\$525.78	-\$55.35
11	\$308.81	\$296.32	\$12.49
12	\$364.19	\$414.60	-\$50.42
Overall Mean	\$399.44	\$421.25	-\$21.81

As discussed previously, experimental yields were typically higher than average on-farm yields, as reported by USDA-NASS. Average profits for all 12 production options for each method were estimated given a 25% and 50% seed cotton yield reduction. With reduced yields, Option 7 provided maximum profits when profits were calculated from the data. For Method 1 and Method 2, Option 1 provided maximum profits at a 25% and 50% yield reduction; however, there was less than a 20 US\$ ac^{-1} difference between Option 1 and 7. Weighting the yield based on a county average may adjust for differences, and is an option for future research.

1.5.4 Limitations

There are three main limitations in this analysis. First, Federal government commodity payments and insurance payouts were not included in this analysis due to the site-specific nature of these payments. Considering government and insurance payments may increase revenue, depending on price assumptions and insurance purchased by the producer, and impact the profitability of the treatments. Secondly, seed technology was limited to herbicide-tolerant cotton varieties and did not include insect-resistant cotton or stacked traits. Results may differ had insect-resistant or stacked trait cotton been included in the experiment. Third, as mentioned above, each plot was harvested on the same date, not at the optimal time based on treatment. The results may differ if the experimental plots had been harvested based on optimal harvest date by treatment. Future research will consider these limitations.

1.6 Summary and Conclusions

Cotton fiber quality attributes have received little attention in the literature. Quality attributes have been mainly used in hedonic price models, not to estimate profitability of specific technologies, although there are exceptions. As discussed earlier, research by Britt, Ramirez, and Carpio (2002) is one such exception. While cotton is grown across the southern portion of the U.S., much of the economic research involving cotton relates to production methods in Texas, which is a much different agronomic region. To the best of our knowledge, this type of research has not been undertaken for cotton production in Alabama.

A contribution of this research was to quantify the impact of row spacing, tillage, and seed traits on profits for cotton producers using two different estimation methods. The first method was to estimate a single equation profit function, where rainfall and production methods were the independent variables. The second method was to estimate multi-equation response functions for seed cotton yield, ginning percentage, and quality attributes (staple, micronaire, strength, and uniformity). Producer profit was then calculated from predicted values for seed cotton yield, ginning percentage, and quality attributes.

Given the 2010 national loan rate, 2010 quality premiums and discounts, and weather conditions during the experiment, estimating a single equation profit function (Method 1) and constructing profit from multi-equation response functions (Method 2) produced similar results; however, when using Method 2 the estimated predicted profits which were larger (on average) than those estimated using Method 1. Method 2 overstated expected profits as compared to both actual profit and predicted profit estimated using Method 1. The use of Method 2 allows for quality attributes to directly influence profitability of different treatments through differences in discounts and premiums applied to the price of cotton received by producers. When estimating profit, the most appropriate method to adopt depends on the purpose of the study and the proposed role of quality.

Additionally, results show that the production option providing the maximum profit to producers was highly dependent on rainfall amounts received during the growing season. The production option utilizing standard row spacing, conventional tillage, and non-transgenic seed (Option 1) was the most profitable under Method 1. Narrow spacing, conventional tillage, and non-transgenic seed (Option 7) was the most profitable under Method 2; however, conservation tillage and non-transgenic seed planted with standard and narrow spacing (Option 4 and 10, respectively) were in the top five most profitable production options regardless of rainfall amount and estimation method. This was not true for Option 7, which performed poorly under drier conditions. Agricultural producers are faced with numerous production options and decisions must be based on what works best for their operation and expected weather conditions.

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Chapter 2

Evaluating Land Tenure Options Considering Dynamic Cropping Decisions

Abstract

Agricultural producers in the Southeast grow a wide variety of crops depending on their geographic location and available markets. In Alabama, cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) are two of the top five crops in terms of production value. The use of crop rotations as compared to monocultures provides agronomic and economic benefits to producers. The objective of this study is to determine the optimal crop rotation for a peanut and cotton producer in Alabama under alternative land tenure arrangements considering previous land use and Markovian prices. The decision to adopt a rotation instead of monoculture is heavily influenced by expected yield, production costs, and expected prices. Assuming the planting time price of cotton at 0.80 US\$ lb^{-1} and the price of peanut at 0.30 US\$ lb^{-1}, a cotton/peanut rotation was the optimal solution. The optimal strategy was similar across land tenure arrangements; however, annualized net returns were different. The land ownership scenario has the lowest annualized net returns, and cash rent flexed on yield scenario has the highest annualized net returns based on the model assumptions.

2.1 Introduction

Agricultural producers in the Southeast grow a wide variety of crops depending on their geographic location and available markets. In Alabama, cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) are two of the top five crops in terms of production value (USDA, 2013a; USDA, 2013b). In 2012, cotton and peanut were planted on 3.80 thousand and 2.20 thousand acres, respectively, and accounted for approximately 44% of Alabama’s total value of commodity production, excluding horticulture crops. Over the last 40 years, acres of planted cotton ranged from 2.19 thousand (low) to 6.10 thousand (high) in 1983 and 2001, respectively. Peanut planted acres increased from 1972 to 1991; however, peanut planted acres steadily declined from 1991 to 2012. With the elimination of the peanut poundage quota (in existence since the Agricultural Adjustment Act of 1938) as part of the Farm Security and Rural Investment Act of 2002, there was a contraction in the number of peanuts farms, a decline in peanut prices, and a change in peanut-farming areas (Dohlman, Foreman, and Da Pra, 2009). Under favorable prices, peanut planted acres increased from 2011 to 2012; however, due to increased stocks, acreage declined in 2013.

The use of crop rotations as compared to monocultures provides benefits to producers due to crop diversification, reduced yield variability, and higher crop yields, particularly for cotton and peanut (Helmers, Yamoah, and Varvel, 2001). Lamb et al. (2007) concluded that net returns to peanut are dependent on irrigation and crop rotations, specifically peanut rotated with cotton or corn (*Zea mays* L.). They estimated that irrigated peanut yields were 1660 lbs ac^{-1} higher in a cotton/cotton/peanut rotation than in a continuous peanut rotation. Peanut grown in rotation with cotton also have a decreased incidence of peanut root-knot nematode and southern blight (Rodríguez-Kábana et al., 1991; Rodríguez-Kábana et al., 1994).

Dynamic programming (DP) models have been used to investigate cropping decisions, such as crop rotations and pest management (Cai et al., 2013; Duffy and

Taylor, 1993; Harper et al., 1994; Livingston, Roberts, and Zhang, 2012; Taylor and Novak, 1992; Taylor and Rodríguez-Kábana, 1999; Zhu, Taylor, and Sarin, 1993). Taylor and Novak (1992) developed a stochastic dynamic programming model to investigate flex cropping and grain storage. Producers using flex cropping based cropping decision on soil moisture, price, weed pressure, and other factors. The objective of their research was to maximize the expected present value of after-tax profit considering soil moisture, the price of wheat (*Triticum aestivum*L.), land use in the previous time period, and grain storage. Taylor and Rodríguez-Kábana (1999) investigated peanut production given pest pressure from soil-born organisms. Crop rotations are the main focus of recent research by Livingston, Roberts, and Zhang (2012) and Cai et al. (2013). Corn-soybean (*Glycine max* Merr.) rotations take center stage in both articles; however, Cai et al. (2013) attempt to develop a dynamic programming model to optimize crop rotations without tying it to a specific region. Results from Livingston, Roberts, and Zhang (2012) are applicable only to northeastern Iowa or areas with similar soils and climate.

Producers must also make land tenure decisions that satisfy the needs of their operations and goals of their landlords. Across the U.S., approximately 38% of farmland was rented by producers in 2007. This percentage differs by state and county. In major crop producing areas of Alabama, the percent of rented land ranged from 30% to more than 50% in 2007 (USDA, 2013c). The types of land tenure arrangements are numerous and differ by crop and location. Substantial research has been conducted examining cash rent (CR) and share rent arrangements; however, little empirical research has investigated flexible cash rental (FCR) arrangements, which are of increasing interest to producers and landowners.

Lichtenberg (2007) investigated the outcome of investment in durable conservation measures either by the landlord or as a requirement for the tenant considering cash rent, share rent, and owner operation. This work noted that the types of tenure agreement and conservation investments are likely to be made concurrently; therefore, tenure agreements should be considered as endogenous, particularly when investigating conservation investment. Apland, Barnes, and Justus (1984) developed a linear programming model to study farm leases in Kentucky. They used an approach similar to the MOTAD[5] model. The objective function considered both the farm operator and the landlord. Five share-rent scenarios and a cash-rent scenario were analyzed, as well as two different levels of risk preference for both the farm operator and landlord. They concluded that the proportion of leased versus owned land and the risk preferences of both the landlord and tenant plays an important role in determining tenure agreements. Myyrä, Pietola, and Yli-Halla (2007) investigated long-term land improvements considering land tenure insecurity on leased land in Finland. Lime and phosphorus applications were identified as long-term land improvements. They concluded that as land tenure insecurity increases, optimal land improvements decrease, thereby resulting in a decline in yields. Perry et al. (1986) developed a simulation model to analyze tenure arrangements and crop rotations for soybeans and rice in Texas; however, their analysis only included different levels of crop-share land tenure arrangements.

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[5] A MOTAD (minimization of total absolute deviations) model is a risk-programming application based on MOTAD decision criteria (Hazell, 1971). The solutions of a MOTAD model can be generated by a linear programming model.

The objective of this study is to determine the optimal crop rotation for a peanut and cotton producer in Alabama under alternative land tenure arrangements.

2.2 Dynamic Programming Model

The objective of the crop rotation model is to maximize the expected present value of returns above variable and fixed costs over a multi-year planning horizon subject to previous land use and to Markovian cotton and peanut prices. Bellman's DP recursive equation for this model is specified as:

$$V_t(PPNT_t, PCOT_t, L_{t-1}) = \max_{x_t, n_t, f_t}\{E[R_t(PPNT_t, PCOT_t, L_{t-1}, x_t, n_t, f_t) + \beta V_{t+1}(PPNT_{t+1}, PCOT_{t+1}, L_t)]\} \tag{2.1}$$

Where

$V_t(\bullet)$ = maximum expected present value of returns over variable, fixed, and land tenure costs from crop year *t* through the end of the planning horizon *T*;

$PPNT_t$ = market price of peanut in crop year *t*;

$PCOT_t$ = market price of cotton lint in crop year *t*;

L_{t-1} = land use state variable in crop year *t - 1*;

x_t= land use decision variable in crop year *t*;

n_t = a binary variable indicating the use of a nematicide in crop year *t*;

f_t = a binary variable indicating the use of a fungicide if the crop is peanut in crop year *t*;

$R_t(\bullet)$ = the function showing annual returns over variable and fixed production costs in crop year *t*;

β = the annual discount factor; and

E = expectation operator, with the expectation taken with respect to the set of stochastic variables in the state transition equation.

The discount factor was assumed to be 0.952 (4.8% real interest rate).

2.3 Empirical Model

As with any modeling exercise, there are a number of components that must be addressed and developed prior to generating results from a model. The following sections outline the experimental methods, the yield response functions, state and decision variables, other input data, estimation of economic return, and land tenure arrangements.

2.3.1 Experimental methods

Cotton and peanut yield response to the previous crop and nematicide and fungicide applications were based on a 17-year field experiment conducted in Headland, Alabama at the Wiregrass Experiment Station. The experiment, coded R-1, was conducted over the 1985 to 2002 time period. Yield results from 1985 to 1990 were published by Rodríguez-Kábana et al. (1991). The soil type was sandy loam and the experiment was a randomized complete block with eight replications. Plots were eight rows 30 feet long and 36 inches wide. Data from this experiment were used to parameterize the DP model because it is one of the few rotational experiments conducted over a sufficiently long time period to fully capture the rotational effects.

Three different crop rotations were considered: continuous peanut (P), cotton/peanut (CP), and cotton/cotton/peanut (CCP). There were two nematicide treatments, with a nematicide (TEM) (one application of *Aldicarb* in the Temik® 15G formulation at 3 lb a.i. ac^{-1}) and without a nematicide (NTEM). In 1994, plots were split to allow for two fungicide treatments, with a fungicide (FOL) (four applications of *Tebuconozole* in the Folicur® 3.6F formulation at 0.255 lb a.i. ac^{-1} $application^{-1}$) and without a fungicide (NFOL). There were a total of 16 treatment alternatives, as shown in

Table 2.1. For example, Treatment 1 (T1) is continuous peanut without a nematicide and fungicide treatment and Treatment 16 (T16) is a cotton/cotton/peanut rotation with a nematicide applied to cotton and peanut and a fungicide treatment for peanut.

Table 2.1. Treatment alternatives from an experiment in Headland, AL at the Wiregrass Experiment Station

Treatment	Rotation	Nematicide (Peanut)	Nematicide (Cotton)	Fungicide (Peanut)
1	Peanut (P)	0	0	0
2	P	0	0	1
3	P	1	0	0
4	P	1	0	1
5	Cotton/Peanut (CP)	0	0	0
6	CP	0	0	1
7	CP	0	1	0
8	CP	0	1	1
9	CP	1	0	0
10	CP	1	0	1
11	CP	1	1	0
12	CP	1	1	1
13	Cotton/Cotton/Peanut (CCP)	0	0	0
14	CCP	0	0	1
15	CCP	1	1	0
16	CCP	1	1	1

Cotton and peanut were planted no earlier than 13 April and no later than 21 May depending on year. Cotton harvest took place between 21 October and 20 November, while peanut were dug between 9 September and 20 October and harvested between 14 September and 27 October. Table 2.2 contains planting and harvest dates for cotton and peanut from 1985 to 2002. The seeding rate for peanut and cotton was 100 lb ac^{-1} and 15 lb ac^{-1}, respectively. Seed varieties Deltapine 90 and Florunner were planted from 1985 to 1997 for cotton and peanut, respectively; however, after 1997, the experiment was established using different seed varieties (Table 2.2). The nematicide was applied prior to planting in an eight to 10 inch band with a Gandy applicator. It was incorporated to a depth of two to three cm after application. The fungicide was applied using a conventional agricultural sprayer delivering 15 gallon ac^{-1}. Cotton and peanut were harvested from a six feet long by 30 feet wide area. Cotton seed yields were converted to cotton lint yields assuming a 40% turnout rate. Summary statistics of the yield data for cotton and peanut are displayed in Table 2.3.

Table 2.2. Planting and harvest dates and seed varieties for cotton and peanut at Headland, AL from 1985 to 2002

Year	Cotton			Peanut				
	Date of:			Date of:				
	Planting	Harvest	Seed Variety	Planting[a]		Dug	Harvest	Seed Variety
				Untreated	Treated			
1985	2 May	4 Nov	Deltapine 90	2 May		1 Oct	10 Oct	Florunner
1986	6 May	10 Nov	Deltapine 90	9 May		13 Oct	17 Oct	Florunner
1987	4 May	21 Oct	Deltapine 90	1 May		22 Sept	25 Sept	Florunner
1988	2 May	4 Nov	Deltapine 90	29 April		29 Sept	6 Oct	Florunner
1989	15 May	25 Oct	Deltapine 90	8 May		22 Sept	4 Oct	Florunner
1990			Deltapine 90	25 April		12 Sept	17 Sept	Florunner
1991	17 May	6 Nov	Deltapine 90	8 May	24 Sept		30 Sept	Florunner
1992	1 May	16 Nov	Deltapine 90	20 April		9 Sept	14 Sept	Florunner
1993	5 May	11 Nov	Deltapine 90	10 May		4 Oct	8 Oct	Florunner
1994	7 May	3 Nov	Deltapine 90	14 May	27 Sept		30 Sept	Florunner
1995	15 May	23 Oct	Deltapine 90	8 May		25 Sept	29 Sept	Florunner
1996			Deltapine 90	16 May		14 Oct	22 Oct	Florunner
1997	9 May	21 Oct	Deltapine 90	24 April	11 Sept		15 Sept	Florunner
1998	21 May	20 Nov	NuCotn 35B	20 May		20 Oct	27 Oct	GK-7
1999	23 April	28 Oct	NuCotn 35B	22 April		11 Sept	15 Sept	Georgia Green
2000	13 April	23 Oct	DPL 685 B/RR	25 April		21 Sept	2 Oct	Georgia Green
2001	3 May	2 Nov	Suregrow 501	3 May		12 Sept	14 Sept	Georgia Green
2002			Suregrow 501	1 May		17 Sept	20 Sept	Georgia Green

[a] Peanut established without a nematicide was designated as untreated and peanut established with a nematicide was designated as treated.

Table 2.3. Summary statistics for cotton lint and peanut yields (lb ac^{-1}) by treatment alternative from 1985 to 2002

Treatment Alternative	1985 - 2002			
	Mean	SD	Min	Max
	Cotton (lb ac^{-1})			
5	759	232	203	1191
7	997	266	348	1636
9	755	236	194	1307
11	939	248	310	1510
13	653	294	97	1452
15	851	296	155	1510
All Treatments	818	290	97	1636
	Peanut (lb ac^{-1})			
1	2122	691	581	4550
2	2674	629	1089	4114
3	2697	743	1162	4308
4	3293	647	1549	4453
5	2593	699	992	3993
6	3254	710	2033	4453
7	2767	708	992	4501
8	3422	594	2347	4453
9	2882	755	1355	4404
10	3434	699	2009	4404
11	3030	684	1476	4816
12	3695	654	2589	4743
13	2757	767	1210	4453
14	3217	393	2372	4066
15	3105	778	1452	4913
16	3812	699	2009	5106
All Treatments	2868	817	581	5106

2.3.2 Peanut and cotton yield response functions

Yield response functions for peanut and cotton lint were estimated using data from the R-1 experiment. Experimental yields are usually found to be higher than average farm-level yields. Taylor and Rodríguez-Kábana (1999) adjusted seed cotton yield and peanut yield by proportionality constants to adjust experimental yields downward to more closely represent average county yields. The experimental yields for this study were produced under supplemental irrigation and heavily managed. Since the majority of cotton and peanut produced in Alabama are not produced under irrigation, the experimental yields are not comparable to published county yields. Therefore, the experimental yields are not adjusted downward.

The yield response functions are mathematically specified as:

$$COTY_t = \gamma_0 + \gamma_1 * L_{t-1} + \gamma_2 * n_t + \gamma_3 * AVGCY_t + \varepsilon_{2,t} \tag{2.2}$$

$$PNY_t = \delta_0 + \delta_1 * L_{t-1} + \delta_2 * n_t + \delta_3 * f_t + \delta_4 * AVGPY_t + \varepsilon_{3,t}, \tag{2.3}$$

where: L_{t-1} is a binary variable for prior year crop in *t-1* (1 = cotton and 0 = peanut); n_t is a binary variable for nematicide treatment (1 = received nematicide treatment, 0 = otherwise) in time *t*; f_t is a binary variable for fungicide treatment for peanut (1 = received fungicide treatment, 0 = otherwise) in time *t*; $AVGCY_t$ and $AVGPY_t$ are average county cotton lint and peanut yields, respectively, in Henry County, Alabama in time *t*; γ and δ are estimated coefficients; and $\varepsilon_{x,t}$ are random error terms for Equations (2.2) and (2.3). The average county yields are a proxy for local weather. They were included in the yield response functions since the average county yields for both cotton lint and peanut are not Markovian for a given rotation, as shown in Table 2.4.

The yield equations were estimated with data from 1985-2002 (SUB1), 1985-1997 (SUB2), and 1994-2002 (SUB3). SUB1 is the entire dataset, SUB2 includes only years where the same seed variety was planted, and SUB3 includes only years where nematicide and fungicide were applied in the experiment. The letters (A, B, etc.) identify different combinations of explanatory variables. For example, SUB3A cotton yield response function includes L_{t-1} as an explanatory variable and SUB3B cotton yield response function does not include L_{t-1} as an explanatory variable. Instead of treatment means, subplot observations were used to estimate yield response functions. The use of subplot observations allows for more variability in cotton and peanut yield.

Table 2.4. Average Henry County yield equations for 1985 to 2002 for cotton and peanut

Variable	1985-2002	
	Cotton	Peanut
Intercept	-1524.37[1]	22195.12
	(13540.18)[2]	(42750.15)
year	1.013	-9.765
	(6.788)	(21.389)
$AVGY_{t-1}$	-0.016	-0.320
	(0.251)	(0.222)
N	17	17

[1] The variables are not statistically significance at the 1%, 5%, and 10% levels.

[2] Standard errors are presented in parentheses below the associated estimated coefficients.

Cotton and peanut yields were estimated using Ordinary Least Squares (OLS), and estimated coefficients are displayed in Tables 2.5 and 2.6, respectively. The estimated response functions for cotton and peanut were then used in Equation (2.1) to estimate net present value (NPV) under different prior year crop and nematicide and fungicide treatment scenarios.

Table 2.5. Crop yield equations for cotton

Variable[1]	Cotton Lint Yield (lbs ac^{-1})			
	SUB1: 1985-2002	SUB2: 1985-1997	SUB3 1994-2002	
			A	B
Intercept	430.929***[2]	511.771***	347.606***	348.178***
	(49.42)[3]	(54.51)	(94.55)	(94.58)
L_{t-1}	-133.129***	-175.567***	-38.774	
	(29.25)	(26.87)	(35.82)	
n_t	195.133***	211.224***	150.04***	150.04***
	(23.13)	(26.87)	(29.28)	(29.29)
$AVGCY_t$	0.595***	0.441***	0.914***	0.897***
	(0.085)	(0.091)	(0.186)	(0.185)
σ[4]	253.39	257.75	219.13	219.22
Adj R^2	0.2370	0.2413	0.1767	0.1760
N	480	368	224	224

[1] L_{t-1} is a binary variable for prior year crop in *t-1* (1 = cotton and 0 = peanut); n_t is a binary variable for nematicide treatment (1 = received nematicide treatment, 0 = otherwise); $AVGCY_t$ is average county cotton lint yields, in Henry County, Alabama; SUB1 is the entire dataset (1985-2002); SUB2 includes only years where the same seed variety was planted (1985 – 1997); SUB3 includes only years where nematicide and fungicide were applied in the experiment (1994 – 2002); letters (A and B) represent different combinations of independent variables.

[2] ***, **, * represents statistical significance at the 1%, 5%, and 10% levels, respectively.

[3] Standard errors are presented in parentheses below the associated estimated coefficients.

[4] σ is the estimated standard deviation (root mean squared error) of the additive random error term.

As shown in Tables 2.5 and 2.6, if the previous crop was cotton, estimated cotton yields are expected to be lower, and estimated peanut yields are expected to be higher. These results support the expected benefit to a crop rotation as opposed to a monoculture. Furthermore, the use of an insecticide was considered beneficial to both cotton and peanut production, and the use of a fungicide was considered beneficial to peanut production. Therefore, it was assumed in the DP model that producers would always choose to apply a nematicide to cotton and a combination of nematicide and fungicide to peanut. Average county yields have a positive correlation with both cotton and peanut yields, as expected. For example, if average county cotton lint yield increased by one lb, cotton lint yield increased by 0.595 lbs based on SUB1. For purposes of the DP model, estimated equations using SUB1 for cotton lint yield and SUB1B for peanut yield were chosen as the preferred equations.

Based on an average county cotton yield of 500 lbs ac^{-1} and the use of a nematicide, cotton lint yield for cotton following cotton is 790.43 lbs ac^{-1} and for cotton following peanut is 923.56 lbs ac^{-1}, which is a 16.84% increase. Assuming a cotton lint price of 0.80 US$ lb^{-1}, the yield increase due to a rotation increases revenue by 106.50 US$ ac^{-1}. Based on an average county peanut yield of 2103 and the adoption of a nematicide and fungicide, the peanut yield for peanut following peanut is 3212.16 lbs ac^{-1} and 3691.671 lbs ac^{-1} for peanut following cotton, an increase of 14.92%. Assuming a peanut price of 0.26 US$ lb^{-1}, the yield increase, due to a rotation, increases revenue by 124.67 US$ ac^{-1}.

Table 2.6. Crop yield equations for peanut

Variable	Peanut Yield (lbs ac^{-1})						
	SUB1: 1985-2002			SUB2: 1985-1997		SUB3: 1994-2002	
	A	B	C	A	B	A	B
Intercept	1850.82***[3]	1799.61***	1778.6***	1373.99***	1293.43***	2640.82***	2210.69***
	(141.13)[4]	(116.82)	(117.26)	(163.01)	(167.15)	(211.00)	(151.33)
L_{t-1}	465.53***	479.51***	451.37***	482.253***	435.52***	488.53***	496.93***
	(57.41)	(44.73)	(47.31)	(66.22)	(69.83)	(70.99)	(50.24)
L_{t-2}			121.43*		212.15**		
			(67.04)		(103.69)		
n_t	414.43***	422.27***	422.27***	422.874***	422.874***	440.96***	439.11***
	(55.83)	(43.54)	(43.49)	(64.79)	(64.56)	(69.22)	(48.99)
f_t		597.02***	598.19***				481.73***
		(45.86)	(45.81)				(48.99)
$AVGPY_t$	0.167***	0.187***	0.196***	0.326***	0.363***	-0.180*	0.031
	(0.063)	(0.052)	(0.052)	(0.071)	(0.073)	(0.097)	(0.068)
σ[2]	723.67	696.69	695.91	697.77	695.36	649.37	649.93
Adj R^2	0.1509	0.2734	0.2751	0.1832	0.1888	0.2088	0.2786
N	672	1024	1024	464	464	352	704

[1] L_{t-1} and L_{t-2} are the binary variables for prior year crops in *t-1* and *t-2* (1 = cotton and 0 = peanut); n_t is a binary variable for nematicide treatment (1 = received nematicide treatment, 0 = otherwise); f_t is a binary variable for fungicide treatment for peanut (1 = received fungicide treatment, 0 = otherwise); $AVGPY_t$ is average peanut yield in Henry County, Alabama; ; SUB1 is the entire dataset (1985-2002); SUB2 includes only years where the same seed variety was planted (1985 – 1997); SUB3 includes only years where nematicide and fungicide were applied in the experiment (1994 – 2002); letters (A, B, C) represent different combinations of independent variables.

[2] In the estimate equations above, σ is the estimated standard deviation (root mean squared error) of the additive random error term.

[3] ***, **, * represents statistical significance at the 1%, 5%, and 10% levels, respectively.

[4] Standard errors are presented in parentheses below the associated estimated coefficients.

2.3.3 State Variables and Transition Probabilities

Cotton lint and peanut price state variables are stochastic and the prior landuse variable is deterministic. Average per unit price data for cotton and peanut was obtained from U.S. Department of Agriculture, National Agricultural Statistics Service (USDA, 2013c) for the years 1982 to 2012 for Alabama. The average cotton lint price is 0.826 US$ lb^{-1}, and the average peanut price is 0.361 US$ lb^{-1}. The average cottonseed price over the same period is 141.67 US$ ton^{-1}. Quality data for cotton lint and peanuts were not available; therefore quality adjustments were not directly considered. Quality was indirectly considered as average per unit price data would include quality adjustments.

Price data were deflated to 2012 constant dollars using the implicit price deflator for gross domestic product (U.S. Department of Commerce, 2013). The two price state variables were discretized into ten states for each, for a total of 100 price states. The states for cotton lint were bound by 0.52 US$ lb^{-1} and 1.02 US$ lb^{-1}, and price states for peanut were bound by 0.16 US$ lb^{-1} and 0.42 US$ lb^{-1}. The deterministic landuse state variable was discretized into 11 states from 0 to 1 by increments of 0.10. There are 1100 total states in the model.

The state transition equations for peanut and cotton lint prices are mathematically specified as:

$$\ln(COTP_t) = \alpha_0 + \alpha_1 * \ln(COTP_{t-1}) + \varepsilon_{4,t} \tag{2.4}$$

$$\ln(PNP_t) = \beta_0 + \beta_1 * \ln(PNP_{t-1}) + \varepsilon_{5,t}, \tag{2.5}$$

where ln(•) is the natural logarithm; $COTP_t$ is price of cotton in *t*; PNP_t is price of peanut in *t*; α and β are estimated coefficients; and $\varepsilon_{x,t}$ are random error terms for Equations (2.4) and (2.5). The above equations were estimated using ordinary least squares (OLS), and the results are displayed in Table 2.7. The cross-prices were not significant, and were not included in the state transition equations. All coefficients associated with lagged price variables are statistically significant (α = 0.01), which indicates that the estimated equations are first-order Markovian.

Table 2.7: Markovian price relationships for cotton and peanut from 1982 to 2012

Variable[1]	Cotton Lint Price	Peanut Price
	(Dependent variables in log form)	
	(US$ lb^{-1})	
Intercept	-0.093*[2]	-0.112
	(0.050)[3]	(0.076)
$\ln(COTP_{t-1})$	0.681***	
	(0.127)	
$\ln(PNP_{t-1})$		0.908***
		(0.067)
σ[4]	0.219	0.129
R^2	0.488	0.860
N	30	

[1] $\ln(COTP_t)$ is the natural log of price of cotton in *t*; $\ln(PNP_t)$ is the natural log of price of peanut in *t*;

[2] ***, **, * represents statistical significance at the 1%, 5%, and 10% levels, respectively.

[3] Standard errors are presented in parentheses below the associated estimated coefficients.

[4] In the estimate equations above, σ is the estimated standard deviation (root mean squared error) of the additive random error term.

The stochastic state transition equations for peanut and cotton lint prices are represented as a matrix of Markovian transition probabilities. The Markov process is the probability of going from the ith price state at time t to the jth price state at time t+1. Since regional cotton and peanut prices are independent, the elements of the full Markovian transition matrix are given by:

$$p = Pr(PPN_t, PCT_t | PPN_{t-1}, PCT_{t-1}) =$$

$$Pr(PPN_t | PPN_{t-1}) * \Pr(PCT_t | PCT_{t-1}), \tag{2.6}$$

where p is the full Markovian transition matrix. The probability $Pr(PPN_t|PPN_{t-1})$ is based on Equation (2.4), and the probability $\Pr(PCT_t|PCT_{t-1})$ is based on Equation (2.5). The prior landuse transition is deterministic. Following Taylor and Rodríguez-Kábana (1999), Equation (2.1) can be rewritten in Markovian DP notation as follows:

$$V_t(PPNT_t, PCOT_t, L_{t-1}) = \max_{x_t, n_t, f_t}\{R_t(PPNT_t, PCOT_t, L_{t-1}, x_t, n_t, f_t) + \beta \sum_{ppnt_{t+1}} \sum_{pcot_{t+1}} \sum_{L_t} [V_{t+1}(PPNT_{t+1}, PCOT_{t+1}, L_t) * Pr(PPN_{t+1}|PPN_t) * \Pr(PCT_{t+1}|PCT_t)]\}. \qquad (2.7)$$

Transition probabilities, based on results in Table 2.7, are presented in Tables 2.8 and 2.9 for cotton and peanut, respectively. The unconditional price probabilities are estimated by p^n, where p is the full Markovian transition matrix as defined above, and n is the number of stages until convergence. Table 2.10 displays the unconditional price probabilities.

Table 2.8. Cotton lint price (PCOT) conditional probabilities

$PCOT_t$	$PCOT_{t+1}$									
	0.52	0.58	0.63	0.69	0.74	0.80	0.85	0.91	0.96	1.02
0.52	0.38582	0.17414	0.14994	0.11203	0.07508	0.04626	0.02669	0.01463	0.00770	0.00771
0.58	0.27230	0.16226	0.15928	0.13426	0.10060	0.06875	0.04371	0.02624	0.01505	0.01757
0.63	0.18608	0.13979	0.15454	0.14530	0.12045	0.09043	0.06277	0.04091	0.02536	0.03436
0.69	0.12409	0.11362	0.14001	0.14547	0.13227	0.10823	0.08140	0.05721	0.03807	0.05963
0.74	0.08125	0.08839	0.12036	0.13711	0.13574	0.12022	0.09737	0.07336	0.05211	0.09409
0.80	0.05249	0.06650	0.09934	0.12323	0.13202	0.12584	0.10916	0.08771	0.06619	0.13752
0.85	0.03359	0.04877	0.07942	0.10666	0.12299	0.12553	0.11608	0.09904	0.07909	0.18883
0.91	0.02135	0.03507	0.06192	0.08957	0.11064	0.12040	0.11820	0.10668	0.08983	0.24633
0.96	0.01351	0.02485	0.04733	0.07341	0.09674	0.11180	0.11612	0.11048	0.09777	0.30798
1.02	0.00853	0.01740	0.03561	0.05899	0.08263	0.10107	0.11070	0.11071	0.10268	0.37167

Table 2.9. Peanut price (PPNT) conditional probabilities

$PPNT_t$	$PPNT_{t+1}$									
	0.16	0.19	0.22	0.25	0.28	0.30	0.33	0.36	0.39	0.42
0.16	0.59145	0.33063	0.07076	0.00677	0.00038	0.00001	0.00000	0.00000	0.00000	0.00000
0.19	0.17437	0.42467	0.30081	0.08588	0.01294	0.00124	0.00009	0.00000	0.00000	0.00000
0.22	0.02626	0.20010	0.38350	0.27270	0.09476	0.01958	0.00277	0.00030	0.00003	0.00000
0.25	0.00243	0.04937	0.22318	0.34716	0.24747	0.09899	0.02574	0.00484	0.00071	0.00010
0.28	0.00016	0.00788	0.07616	0.23554	0.31522	0.22523	0.10005	0.03092	0.00723	0.00162
0.30	0.00001	0.00093	0.01786	0.10216	0.23968	0.28716	0.20572	0.09904	0.03499	0.01245
0.33	0.00000	0.00009	0.00320	0.03199	0.12463	0.23803	0.26247	0.18860	0.09676	0.05425
0.36	0.00000	0.00001	0.00047	0.00787	0.04872	0.14234	0.23252	0.24068	0.17352	0.15387
0.39	0.00000	0.00000	0.00006	0.00162	0.01533	0.06620	0.15516	0.22459	0.22138	0.31567
0.42	0.00000	0.00000	0.00001	0.00029	0.00408	0.02531	0.08284	0.16352	0.21527	0.50868

Table 2.10. Unconditional price probabilities for cotton lint and peanut

	Price of Cotton Lint ($PCOT_{t+1}$) in US$ lb^{-1}									
	0.52	0.58	0.63	0.79	0.74	0.80	0.85	0.91	0.96	1.02
Unconditional Probability	0.1300	0.0924	0.1085	0.1139	0.1099	0.0992	0.0847	0.0691	0.0542	0.1382
	Price of Peanut ($PPNT_{t+1}$) in US$ lb^{-1}									
	0.16	0.19	0.22	0.25	0.28	0.30	0.33	0.36	0.39	0.42
Unconditional Probability	0.0412	0.0774	0.1142	0.1371	0.1421	0.1322	0.1133	0.0902	0.0655	0.0867

2.3.4 Decision Variables

The initial decision variables for the model were landuse, adoption of nematicide use, and adoption of fungicide use. As stated earlier, based on yield response functions, it is assumed that producers always choose to adopt nematicide and fungicide treatments; therefore landuse is the only decision variable endogenous in the DP model. The landuse decision variable was discretized to coincide with the landuse state variable (as shown in Appendix A). Decisions ranged from 0 to 1 divided by increments of 0.10. A producer must decide what proportion of acreage to allocate to cotton and peanut production.

2.3.5 Other input data

Variable and fixed costs, excluding land tenure costs, for cotton and peanut production were included in the study, and were based on 2012 Alabama and Georgia Crop Enterprise Budgets (Alabama Cooperative Extension System, 2012; University of Georgia, 2012), 2012 input data from Mississippi State University (Mississippi State University, 2012), and production data associated with the experiment. Machinery was selected to represent equipment needed on a typical 1000 acre cotton and peanut farm in Alabama. Production costs can be classified as variable costs, variable costs as a function of yield, and fixed costs. While the experiment received supplemental irrigation, the irrigation data were not available, and it is unknown the amount of irrigation water applied during each year of the experiment. The average rainfall from April to October over the experimental period was 32.29 inches.[6] Rainfall from April to October was more than one standard deviation from the mean in only two out of the 18 years of the experiment (1990 and 2000). Based on the rainfall data and personal correspondence with

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[6] Rainfall data was procured from AWIS Weather Service.

the lead scientist on the experiment, it appears that irrigation was only applied during two out of the 18 years in the experiment, which were extremely dry years in the area.[7] The average experimental yield was comparable to yield goals used to establish enterprise budgets for cotton and peanut production in Alabama, which were assumed to be dryland; therefore, irrigation costs were not included in production costs. Interest on operating capital was calculated for six months assuming an interest rate of 5.56%.[8] Operating capital was assumed to include variable costs plus land rent paid prior to planting.

For cotton, variable costs as a function of yield were costs associated with ginning, storage and warehousing, and promotions, boards, and classing. For peanut, the yield varying costs were cleaning, drying, marketing, and National Peanut Board (NPB) Check-off. Fixed costs do not change with output level, and include machinery depreciation, taxes, insurance, and housing, as well as, general overhead and management, which were assumed to be 10% of variable costs (5% each). An example enterprise budget for cotton and peanut is displayed in Table 2.11 assuming cotton lint yield of 892 and peanut yield of 3617.

In the model, for cotton production assuming a nematicide treatment, the per-acre costs consist of variable costs of 408.87 US\$ ac^{-1} and fixed costs of 161.43 US\$ ac^{-1}, regardless of yield and above land tenure costs. Similarly, for peanut production assuming a nematicide and fungicide treatment, the per-acre costs consist of variable costs of 533.28 US\$ ac^{-1} and fixed costs of 174.10 US\$ ac^{-1}. Based on production costs

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[7] Based on personal correspondence with Dr. Rod Rodríguez-Kábana

[8] This is the average fixed interest rate on other operating loans in the Eighth (St. Louis) Federal Reserve District from Quarter 4 2012 (Federal Reserve Bank of St. Louis, 2013)

and assumed yields in Table 2.11, the total variable cost (total variable costs plus yield varying costs) breakeven price is approximately 0.57 US\$ lb^{-1} and 0.16 US\$ lb^{-1}, respectively, for cotton and peanut. The breakeven prices for cotton and peanut are at the lower end of the range of price states used in the model.

2.3.7 Estimating economic return

The annual economic return equation is defined as:

$$R_t = [\{((PCOT_t - vycot) * COTY_t) - vcot - lt\} * (CC_t + PC_t)] + [\{((PPNT_t - vypnt) * PNTY_t) - vpnt - lt\} * (PP_t + CP_t)] \tag{2.8}$$

where $PCOT_t$ and $PPNT_t$ are price of cotton and peanut in US\$ lb^{-1}, respectively; $COTY_t$ and $PNTY_t$ are yields of cotton and peanut in lbs ac^{-1} (which depends on previous crop and production methods), respectively; $vycot$ and *vypnt* are variable costs of producing cotton and peanut dependent on yield; $vcot$ and *vpnt* are variable costs of cotton and peanut not dependent on yield; *lt* is cost of land tenure; and CC_t, PC_t, PP_t, and CP_t are the portion of land planted to cotton following cotton, cotton following peanut, peanut following peanut, and peanut following cotton, respectively. The economic return is affected by cotton lint and peanut yield and prices, land tenure arrangements, and total variable costs. The expected cotton and peanut prices are assumed to be the “from” price, since producers routinely contract their cotton and peanut production prior to planting.

Table 2.11. Per acre production costs for cotton and peanut in 2012 dollars assuming average experimental yield and adoption of nematicide and fungicide treatments

Cost Components	Cotton	Peanut
	US$ ac^{-1}	
Variable Costs		
Seed	$18.93	$140.00
Inoculant		$7.25
Lime	$11.55	$50.50
Fertilizer	$104.23	$2.63
Weed Control	$63.26	$55.55
Insect Control	$31.41	$57.73
Disease Control		$7.02
PGR	$1.08	
Defoliant and Boll Opener	$13.00	
Machinery		
Fuel	$59.59	$69.32
Repairs and Maintenance	$38.41	$46.12
Labor	$28.35	$31.74
Crop Insurance	$28.00	$51.00
Interest on Operating Capital (5.56%)	$11.06	$14.42
Total Variable Costs	$408.87	$533.28
Yield Varying Costs[1]		
Ginning	$71.36	
Storage and Warehousing	$19.51	
Promotions, Boards, and Classing	$12.67	
Cleaning		$7.16
Drying		$36.35
Marketing		$5.43
National Peanut Board Checkoff		$6.42
Total Yield Varying Costs	$103.54	$55.36
Fixed Costs		
Machinery Depreciation, Taxes, Insurance, and Housing	$120.54	$120.78
General Overhead	$20.44	$26.66
Management	$20.44	$26.66
Total Fixed Costs	$161.43	$174.10
Total Costs Excluding Land	$673.84	$762.74

[1] Assumes cotton lint yield of 892 lbs ac^{-1} and peanut yield of 3617 lbs ac^{-1}.

2.3.8 Land tenure arrangement scenarios

Six farmland land tenure arrangement scenarios were considered: ownership with loan payments (OWN), CR, flexible cash rent for crop price (FCRP), flexible cash rent for crop yield (FCRY), and flexible cash rent for revenue (FCRR). The initial assumptions are displayed in Table 2.12. The average dryland land value in Alabama for 2012 was 2,300 US\$ ac^{-1}, and was considered the average purchase price for calculating land ownership costs (USDA, 2013c). Ownership costs were based on a 25 year loan with a 25% down payment and a 5.26% interest[9] rate plus a tax of 8.79 US\$ ac^{-1} (based on a tax rate of 10% and a county mill rate of 0.037). The assumed cash rent was 50 US\$ ac^{-1}, which was similar to the average dryland cash rent in Henry County, AL in 2012 of 45 US\$ ac^{-1} (USDA, 2013c).

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[9] This is the average fixed interest rate on farm real estate loans in the Eighth (St. Louis) Federal Reserve District from Quarter 4 2012 (Federal Reserve Bank of St. Louis, 2013)

Table 2.12. Land tenure assumptions

Variable	**Value**	**Unit**
Land Value	2,300.00	US$ ac^{-1}
Down payment	25	%
Loan Amount	1,725.00	US$ ac^{-1}
Real Estate Interest Rate	5.26	%
Term of loan	25	years
Annual Payment	125.60	US$ ac^{-1}
Tax Rate	10	%
County Mill Rate	3.7	%
Per Acre Tax	8.51	US$ ac^{-1}
Cash Rent	50.00	US$ ac^{-1}
Base Rent	50.00	US$ ac^{-1}
Base Cotton Price	0.73	US$ lb^{-1}
Base Peanut Price	0.26	US$ lb^{-1}
Base Cotton Yield	892	lb ac^{-1}
Base Peanut Yield	3617	lb ac^{-1}
Base Cotton Revenue	651.16	US$ ac^{-1}
Base Peanut Revenue	940.42	US$ ac^{-1}
Minimum Rent	25.00	US$ ac^{-1}
Maximum Rent	75.00	US$ ac^{-1}

As discussed previously, there are numerous ways to estimate flexible cash rents; however, for purpose of this study, flexible cash rents are calculated using the percent change method. The following equations are used to calculate flexible cash rents based on price, yield, and revenue, respectively:

$$FCRP = BCR + \left(BCR * \left(\frac{FP-EP}{EP}\right)\right) \tag{2.9}$$

$$FCRY = BCR + \left(BCR * \left(\frac{FY-EY}{EY}\right)\right) \tag{2.10}$$

$$FCRR = BCR + \left(BCR * \left(\frac{FR-ER}{ER}\right)\right) \tag{2.11}$$

where *BCR* is base cash rent; *FP, FY,* and *FR* are final price, yield, and revenue, respectively; and *EP, EY,* and *ER* are expected price, yield, and revenue respectively.

The base rent was set equal to the cash rent in the base scenario and the minimum and maximum rents were set 25 US$ ac^{-1} below and above the base rent. Expected prices for cotton lint and peanut were the average price received by producers from 2008 to 2012. Expected yields for cotton lint and peanut were the average yield from the experimental data assuming adoption of nematicide and fungicide treatments. Expected revenue for each crop was the expected price multiplied by the expected yield. Ownership costs were included as fixed costs, while cash rent and flexible cash rent costs were included as variable costs. Therefore, it was assumed that producers make an initial rent payment to the landlord equal to the cash rent or minimum rent (depending on scenario) prior to planting which was included in the calculation of interest on operating capital. Rental payments were also included in the calculation of general overhead and management.

As the actual value (price, yield, or revenue) increases (decreases) relative to the base value (price, yield, or revenue), the flexible cash rent increases (decreases). If the base value is set too high, tenants face higher land tenure costs. If the base value is set too low, landlords face lower land tenure revenue. The FRCP for various base and actual cotton lint and peanut prices are shown in Table 2.13, assuming a base rent of 50 US$ ac^{-1}. Table 2.14 displays the FCRR for various revenue levels by crop rotation. There are four FCRY in the model, given the assumptions in Table 2.12, and they are 44.31 US$ ac^{-1} for continuous cotton, 51.77 US$ ac^{-1} for cotton following peanut, 44.40 US$ ac^{-1} for continuous peanut, and 51.03 US$ ac^{-1} for peanut following cotton. Flexible cash rents are subject to minimum and maximums (as shown in Table 2.12) and the true cost of the rent must include the increase in interest on operating capital as well as general overhead and management. It is assumed that rental agreements are not subject to termination over the period of analysis.

Table 2.13. Cash rent flexed on price (FCRP) by crop

Actual Cotton Lint Price (US\$ ac^{-1})	Base Cotton Lint Price (US\$ ac^{-1})			Actual Peanut Price (US\$ ac^{-1})	Base Peanut Price (US\$ ac^{-1})		
	0.52	0.73	1.02		0.16	0.26	0.42
0.52	50.00	35.62	25.49	0.16	50.00	30.77	19.05
0.58	55.34	39.42	28.21	0.19	59.03	36.32	22.49
0.63	60.68	43.23	30.94	0.22	68.06	41.88	25.93
0.69	66.03	47.03	33.66	0.25	77.08	47.44	29.37
0.74	71.37	50.84	36.38	0.28	86.11	52.99	32.80
0.80	76.71	54.64	39.11	0.30	95.14	58.55	36.24
0.85	82.05	58.45	41.83	0.33	104.17	64.10	39.68
0.91	87.39	62.25	44.55	0.36	113.19	69.66	43.12
0.96	92.74	66.06	47.28	0.39	122.22	75.21	46.56
1.02	98.08	69.86	50.00	0.42	131.25	80.77	50.00

Table 2.14. Cash rent flexed on revenue (FCRR) by crop and rotation

Cotton				Peanut			
Continuous		Following Peanut		Continuous		Following Cotton	
Actual Revenue	FCRP	Actual Revenue	FCRP	Actual Revenue	FCRP	Actual Revenue	FCRP
US\$ ac^{-1}							
411.03	31.56	480.25	36.88	513.95	27.33	590.67	31.40
458.45	34.93	535.67	40.82	610.31	32.26	701.42	37.07
505.88	38.30	591.08	44.76	706.68	37.19	812.17	42.74
553.30	41.68	646.49	48.70	803.04	42.13	922.92	48.42
600.73	45.05	701.91	52.64	899.40	47.06	1033.67	54.09
648.16	48.42	757.32	56.58	995.77	51.99	1144.42	59.76
695.58	51.79	812.73	60.52	1092.13	56.93	1255.17	65.43
743.01	55.16	868.15	64.46	1188.50	61.86	1365.92	71.10
790.43	58.54	923.56	68.40	1284.86	66.80	1476.67	76.77
837.86	61.91	978.98	72.34	1381.23	71.73	1587.42	82.44

2.4 Results and Discussion

Due to the large number of states in the DP model, only a subset of the optimal solution is presented in the article. The complete optimal solution for the CR scenario is found in Appendix B.[10] The optimal decision rule in the DP model converged by at least the thirteenth stage (t = 13) for each scenario. The decision rule is applicable to years one through 13, assuming a planning horizon of 25 years. For longer planning horizons, the decision ruled holds until the current time period is within 12 years of the end of the planning horizon.

Tables 2.15, 2.16, and 2.17 present the optimal decision rule (or matrix) for all combinations of peanut and cotton lint prices holding the previous land use constant at 0% cotton, 50% cotton, and 100% cotton, respectively. The five panels in each table are for each land tenure arrangement scenario. Assuming prior year landuse is 0% cotton (100% peanut) and with price of cotton at 0.80 US\$ lb^{-1} and price of peanut at 0.30 US\$ lb^{-1}, producers should plant 100% cotton (Table 2.15). As the price of peanut increase, while holding the price of cotton constant, producers should plant continuous peanut, and as the price of peanut decreases, producers should plant cotton following peanut. These results are the same regardless of land tenure arrangements with few exceptions.

As prior year landuse adjusts from 0% cotton to 50% cotton, producers choose more of a rotation (Table 2.16). Assuming prior year landuse is 50% cotton (50% peanut) and with the price of cotton at 0.80 US\$ lb^{-1} and the price of peanut at 0.30 US\$ lb^{-1}, producers maintain a cotton/peanut rotation. As the price of peanut increases (relative to

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[10] A full decision rule is available from the author on request.

the price of cotton) the optimal strategy, from an economic perspective, is to grow continuous peanut. As the price of cotton increases (relative to the price of peanut) the optimal strategy is to grow continuous cotton. Once again, the results are similar regardless of land tenure arrangement.

As prior year landuse adjusts from 50% cotton to 100% cotton, producers continue to maintain a rotation (Table 2.17). Assuming prior year landuse is 100% cotton (0% peanut) and with the price of cotton at 0.80 US\$ lb^{-1} and the price of peanut at 0.30 US\$ lb^{-1}, producers maintain a cotton/peanut rotation. Once again, the optimal strategy is to grow continuous peanut when the cotton/peanut price ratio is closer to one and to grow continuous cotton at higher ratios.

Over a five-year period, assuming prices stay constant at 0.80 US\$ lb^{-1} for cotton lint and 0.30 US\$ lb^{-1} for peanut, and the producer grew 100% peanut in stage t-1, the optimal rotation is: $100\%\ peanuts_{t-1}$: $100\%\ cotton_{t}$: $100\%\ peanuts_{t+1}$: $100\%\ cotton_{t+2}$: $100\%\ peanuts_{t+3}$: $100\%\ cotton_{t+4}$, where ":" is the divider between years in rotation. This is the optimal strategy for all land tenure arrangements, except for FCRY. The optimal strategy for FCRY is: $100\%\ peanuts_{t-1}$: $90\%\ cotton_{t}\ and\ 10\%\ peanuts_{t}$: $10\%\ cotton_{t+1}\ and\ 90\%\ peanuts_{t+1}$: $90\%\ cotton_{t+2}\ and\ 10\%\ peanuts_{t+2}$: $10\%\ cotton_{t+3}\ and\ 90\%\ peanuts_{t+3}$: $90\%\ cotton_{t+4}\ and\ 10\%\ peanuts_{t+4}$. These results are displayed in Tables 2.15 – 2.17 and in Appendix B.

The yield increase due to a rotation, ratio of cotton price to peanut price, along with production costs, drives the rotation decision. Although there is a definite yield increase due to rotating cotton and peanut, the yield increase is not enough to overcome the difference in overall yield potential and production costs given high peanut prices and low cotton prices. If the panels in Tables 2.15, 2.16, and 2.17 were broken into four quadrants, for peanut prices greater than or equal 0.30 US$ lb^{-1} and cotton prices less than 0.80 US$ lb^{-1}, producers would plant continuous peanut. Using the cotton lint and peanut yields from the respective production functions, the breakeven prices excluding land tenure costs were 0.849 US$ lb^{-1} for continuous cotton; 0.745 US$ lb^{-1} for cotton following peanut; 0.237 US$ lb^{-1} for continuous peanut; and 0.208 US$ lb^{-1} for peanut following cotton.

Table 2.15. Optimal decision rule with 100% peanut in (t-1) by tenure arrangement

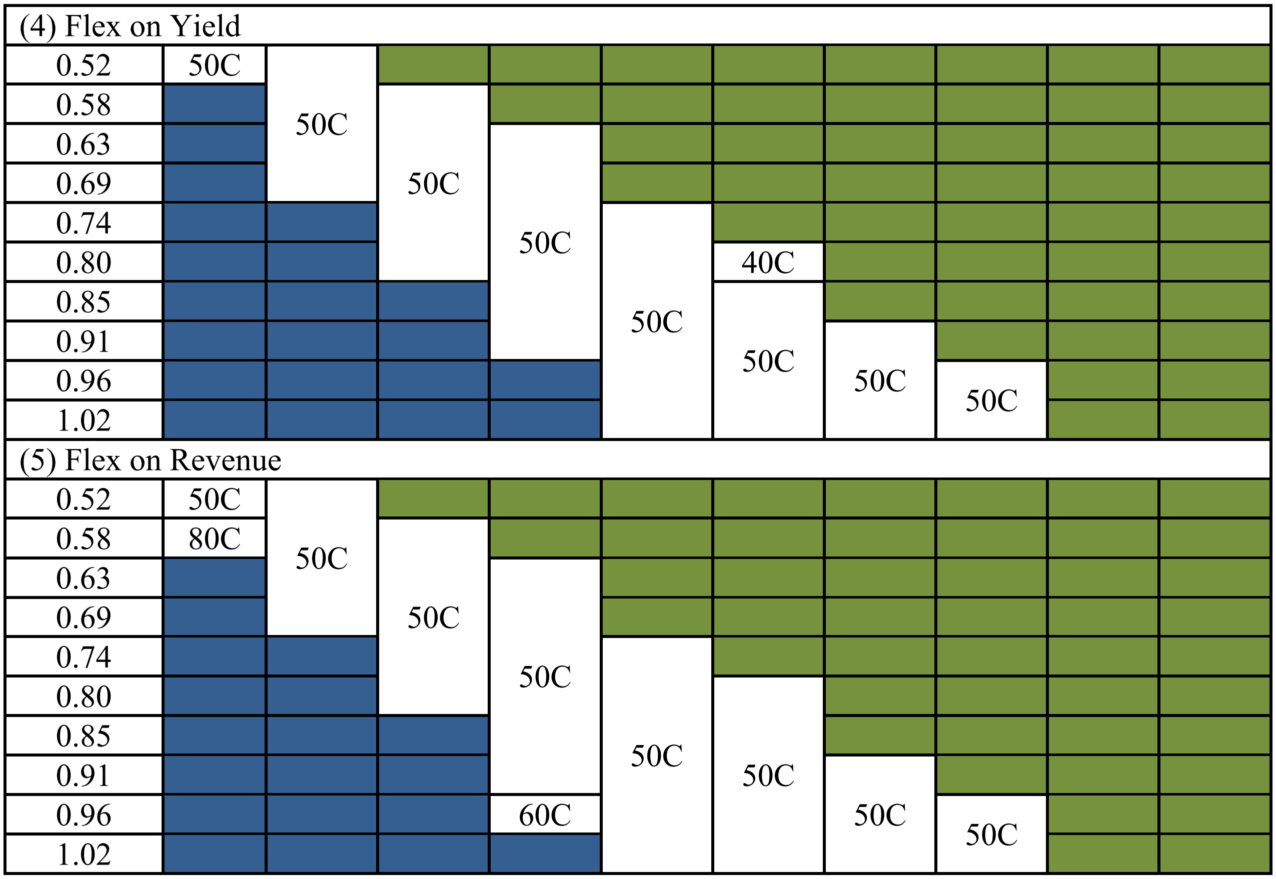
Cotton lint price (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.16	0.19	0.22	0.25	0.28	0.30	0.33	0.36	0.39	0.42
(1) Ownership										
0.52	🟦	🟦	30C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟦	🟦	10C	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	90C	🟩
(2) Cash Rent										
0.52	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	90C	🟩
(3) Flex on Price										
0.52	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩

(4) Flex on Yield										
0.52	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟦	90C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
(5) Flex on Revenue										
0.52	🟦	🟦	40C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres or percent of P acres. For example, 90C is 90% Cotton and 10% Peanut.

Table 2.16. Optimal decision rule with 50% cotton in (t-1) by tenure arrangement

Cotton lint price (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.16	0.19	0.22	0.25	0.28	0.30	0.33	0.36	0.39	0.42
(1) Ownership										
0.52	50C	50C	30C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	60C		50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			50C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			50C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				50C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				50C	🟩	🟩	🟩
0.91	🟦	🟦	🟦					🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				50C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					30C	🟩
(2) Cash Rent										
0.52	50C	50C	10C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	80C		50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			50C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			50C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				50C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				50C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				50C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					50C	🟩
(3) Flex on Price										
0.52	50C	50C	50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58				🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			50C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				50C	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦				🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				50C	🟩	🟩	🟩	🟩
0.85	🟦	🟦					50C	🟩	🟩	🟩
0.91	🟦	🟦	🟦					🟩	🟩	🟩
0.96	🟦	🟦	🟦					50C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					50C	🟩



(4) Flex on Yield										
0.52	50C	50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦		50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			50C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			50C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				40C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦			50C	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				50C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				50C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					🟩	🟩
(5) Flex on Revenue										
0.52	50C	50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	80C		50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			50C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			50C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				50C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				50C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	60C				50C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					🟩	🟩

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres or percent of P acres. For example, 90C is 90% Cotton and 10% Peanut.

Table 2.17. Optimal decision rule with 100% cotton in (t-1) by tenure arrangement

Cotton lint price (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.16	0.19	0.22	0.25	0.28	0.30	0.33	0.36	0.39	0.42
(1) Ownership										
0.52	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	30C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
(2) Cash Rent										
0.52	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
(3) Flex on Price										
0.52	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩

(4) Flex on Yield										
0.52	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
(5) Flex on Revenue										
0.52	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	70C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.96	🟦	🟦	🟦	10C	🟩	🟩	🟩	🟩	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres or percent of P acres. For example, 90C is 90% Cotton and 10% Peanut.

Annualized net returns[11] for the optimal strategy for each scenario were calculated from the present value of returns over variable and fixed costs, including land tenure costs. The present value of returns over variable and fixed costs and annualized net returns are displayed in Table 2.18. The scenario with the highest annualized net returns was FCRY at 209.47 US\$ ac^{-1}, followed by CR (206.17 US\$ ac^{-1}), FCRR (198.94 US\$ ac^{-1}), FCRP (196.40 US\$ ac^{-1}), and OWN (126.45 US\$ ac^{-1}). The model did not consider

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[11] Annualized net returns were calculated as the present value of returns over variable and fixed costs divided by 14.3809, which is the uniform series present value over 25 years at an interest rate of 4.8% $[USPV_{4.8,25}]$.

aesthetic or other benefits of land ownership, such as having a home base for the operation and potential increase in net worth through land value appreciation or decrease in net worth from the decline in real land values. It was interesting to note that over the long-term, a standard CR scenario has higher returns than FCRP and FCRR scenarios. The profitability of a FCRR scenario is dependent on the model assumptions. If the base cotton and/or peanut prices were increased, FCRP would decrease, as would FCRR. The unconditional expected frequencies in Table 2.19 demonstrate that (regardless of scenario) the probability of a producer planting peanut is higher than the probability of a producer planting cotton. A rotation is more probable under OWN, CR, and FCRR.

Table 2.18. Present value of returns over variable and fixed costs and annualized net returns by scenario

Scenario	Present value of returns over variable and fixed costs	Annualized net returns
	US$ ac^{-1}	
OWN	1818.43	126.45
CR	2964.95	206.17
FCRP	2824.35	196.40
FCRY	3012.32	209.47
FCRR	2860.93	198.94

Table 2.19. Unconditional expected frequencies of cotton and peanut in the optimal solution by tenure arrangement

Percent Cotton Acres	OWN	CR	FCRP	FCRY	FCRR
0	0.620341	0.649254	0.640527	0.649456	0.637413
10	0.012853	0.002697	0.000000	0.006280	0.006821
20	0.002326	0.000039	0.000000	0.000000	0.000000
30	0.016086	0.000000	0.000000	0.000000	0.001653
40	0.000007	0.000014	0.000000	0.000000	0.012805
50	0.000599	0.000000	0.000000	0.000000	0.000000
60	0.000016	0.000007	0.000000	0.000000	0.007047
70	0.008835	0.000000	0.000000	0.000000	0.003423
80	0.001253	0.000101	0.000000	0.000000	0.000000
90	0.012685	0.008079	0.000000	0.012587	0.004287
100	0.324999	0.339808	0.359473	0.331676	0.326551

2.4.1 Assumptions and Limitations

There are three main limitations in this analysis. First, Federal government commodity payments and insurance payouts were not included in this analysis due to the site-specific nature of these payments and due to uncertainty about the continuation of current insurance program. Considering government and insurance payments may increase revenue, depending on price assumptions and insurance purchased by the producer, and impact results of the DP model. Secondly, based on the assumptions in the DP model, continuous peanuts were the economically optimal solution given high peanut prices and low cotton prices; however, as identified in the literature, continuous peanuts may not be sustainable from an agronomic perspective due to increased disease pressure (Godsey, et al., 2007; Jordan et al., 2002; Lamb et al., 2007; Rodríguez-Kábana et al., 1991; Rodríguez-Kábana et al., 1994). When deciding on a rotation, producers must consider all aspects of production and their operation. Third, the land tenure arrangements are highly dependent on the assumptions made in the model. Changing the parameters may change the optimal strategy by land tenure arrangement. These limitations provide additional questions may play important role in future research.

2.5 Summary and Conclusions

Agricultural producers are faced with numerous production decisions from the allocation of land to a particular crop to the appropriate rental agreement. In recent years, landowners have increased cash rents in an attempt to capitalize on higher commodity prices and yields. While these increases were larger in corn and soybean producing areas of the United States, the potential for rent increases exists across the United States. Producers incur the majority of risk associated with fixed cash rent due to the potential for lower harvest prices and yields. Cash rents flexed on price, yield, or revenue provide downside protection for producers and compensate landowners when prices and/or yields are above average. Although this analysis was conducted using a specific model with data from a data set limited to one location, it can be argued that the results are applicable to the peanut and cotton producing region of the southeastern U.S., particularly the wiregrass area of southern Alabama and Georgia.

As expected, the decision to adopt a rotation instead of monoculture is heavily influenced by expected yield, production costs, and expected prices. From an agronomic perspective, there are numerous benefits to adopting a rotation, including a lower incidence of peanut root-knot nematodes and southern blight, and subsequent yield increases. However, the peanut yield increase following cotton and the cotton yield increase following peanut, as estimated based on the experimental data from Headland, AL, were not large enough to justify the inclusion of cotton in the rotation at high peanut prices and peanut in rotation at high cotton prices. Assuming the price of cotton at 0.80

US$ lb^{-1} and the price of peanut at 0.30 US$ lb^{-1}, a cotton/peanut rotation was the optimal solution.

The optimal strategy was similar across land tenure arrangements; however, annualized net returns were different. The OWN scenario has the lowest annualized net returns, and FCRY has the highest annualized net returns based on the model assumptions. The key to successful flexible cash rental arrangements is setting a realistic base rent, price, yield, and revenue, and identifying how the producer will identify the actual price, yield, and revenue used in the flexible cash rent calculations. With fluctuations in market prices for commodities, standard cash rental arrangements may not be the most appropriate land tenure arrangements for producers and landowners. The use of crop rotations, such as a cotton/peanut rotation, as well as flexible cash rental arrangements provides producers with opportunities to maximize their net revenue above variable and fixed costs.

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Chapter 3

Evaluating Land Tenure Options Considering Dynamic Cropping Decisions: A Safety-First Approach

Abstract

Annually, agricultural producers are faced with production risk in many forms including unpredictable weather, pest pressure, rotational considerations, and a volatile commodity market. The objective of this study is to incorporate a safety-first constraint into a dynamic programming model to determine the optimal crop rotation for a peanut and cotton producer in Alabama under alternative land tenure arrangements assuming a producer can choose to leave land fallow. Adopting a peanut/cotton crop rotation with the option of fallowing with consideration given to the type of land tenure arrangement may be an appropriate risk management option for producers. As shown in Chapter 2, the decision to adopt a rotation instead of monoculture is heavily influenced by expected yield (which is dependent on prior year crop), production costs, and expected prices.

3.1 Introduction

Annually, agricultural producers are faced with production risk in many forms including unpredictable weather, pest pressure, rotational considerations, and a volatile commodity market. There is substantial literature related to risk in agriculture production. In 2002, *A Comprehensive Assessment of the role of Risk in U.S. Agriculture (*Just and Pope, 2002) was published with the intent of providing a reference book for economists interested in agricultural risk. Prior to this book, the last comprehensive book on agricultural risk was *Risk and Uncertainty in Agricultural Development (*Roumasset and Boussard, 1979). Just and Pope (2002) complied papers from leading experts in agricultural risk covering topics from risk models to the significance of agricultural risk research. In 2003, the Journal Agricultural Systems devoted an entire issue to risk research in agriculture ranging from a discussion on risk versus uncertainty (Taylor, 2003) to a summary of opportunities and challenges facing researchers investigating risk in agricultural economics (Just, 2003).

Risk in agriculture is obvious, but less obvious is the importance of risk perceptions to agricultural producers. Do agricultural producers really care about risk? Based on research published in 1985, crop producers are concerned with variability related to weather, output prices, and production costs (Patrick et al., 1985). In the southeastern U.S., producers who grow a variety of crops are particularly concerned with crop diversification and production practices (Patrick et al., 1985). In the literature, there are three prominent theories for measuring risk preferences: expected utility (EU) theory, safety-first formulations, and prospect theory.

The basic premise of EU theory is that decision makers maximize expected utility. While the modern theory was first introduced by von Neumann and Morgenstern (1944), EU theory predates Adam Smith. Meyer (2002) provides a detailed summary of the history of the EU decision model and how it has been and is currently being used to measure risk preferences of agricultural producers. The use of an EU decision model is prevalent in agricultural economics literature (Howitt et al., 2005; Knapp and Olson, 1996; Krautkraemer, van Kooten, and Young, 1992; and Shively, 2000). However, there is literature that examines how the behavior of decision makers may violate EU assumptions, such as the independence axiom (Buschena, 2002).

The decision making process of many producers plausibly includes safety-first considerations where they are more concerned about the possibility of low income than the variability (variance) of income per se (Musser, Patrick, and Eckman, 1996; Patrick et al., 1985). Safety-first formulations were first introduced by Roy (1952), followed by Telser (1956) and Kataoka (1963), and are well represented in the literature (Atwood and Buschena, 2003; Hatch, Atwood, and Segar, 1989; Krautkraemer, van Kooten, and Young, 1992; Qiu, Prato, and McCamley, 2001; Watkins, Anders, and Windham, 2004). Roy (1952) assumes that decision makers strive to minimize the probability of a disaster income level (Levy and Levy, 2009). Telser (1956) assumes that a decision maker maximizes their expected net income for a given level of risk and disaster level. Similar to Roy (1952) and Telser (1956), Kataoka's (1963) model maximizes a critical income level subject to the probability of net income being less than the critical income level is less than a given level of risk (Atwood and Buschena, 2003). Recently, safety-first formulations have been utilized to explore a variety of topics, such as investigating fixed rotation grazing strategies (Jakoby et al., 2013) and measuring the impact of price variability on risk preferences (Arnade and Cooper, 2012).

Prospect theory was first proposed by Kahneman and Tversky (1979) as an alternative to EU theory when investigating choice under risk. Under prospect theory, there are two stages related to the choice process: editing and evaluation. In the editing stage, the decision maker organizes outcomes associated with each prospect to simplify the evaluation stage. For example, outcomes are defined as gains and losses from a reference point. In the evaluation stage, the decision maker evaluates each prospect and chooses the prospect that maximizes the overall value of the edited decision. Collins, Musser, and Mason (1991) utilized prospect theory to investigate risk preferences of grass seed growers in Oregon. In 1992, Tversky and Kahneman (1992) proposed a new version of prospect theory called cumulative prospect theory. The cumulative prospect theory utilizes the cumulative distribution function, which satisfies stochastic dominance.[12]

Recently, there has been an increased interest in exploring the efficiency of EU theory at describing decision-making when considering risk. Levy and Levy (2009) demonstrate through experiments that safety-first is an important consideration when choosing investments; however, they advocate for considering safety-first along with EU theory. Bocquého, Jacquet, and Reynaud (2014) investigated French farmers' risk preferences considering EU theory and cumulative prospect theory. They concluded that on average farmers are risk averse (assuming EU theory); however, they find that cumulative prospect theory provides additional details regarding farmers' behavior. In their experiment, farmers exhibit loss aversion (i.e., putting a higher value on loss than on

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[12] Stochastic dominance (also referred to as first degree stochastic dominance), as defined in Hadar and Russell (1969), is the condition that the "value of the cumulative distribution of the preferred prospect never exceeds that of the inferior prospect." Second degree stochastic dominance is weaker than first degree stochastic dominance. This condition holds when the area under a prospect's cumulative distribution is greater than or equal to the cumulative distribution for the other prospect(s) (Hadar and Russell, 1969).

equal gains) and tend to put more emphasis on events with a low probability of occurrence.

Expected Utility theory and safety-first formulations have been incorporated into dynamic programming models to investigate a variety of subjects. Blakeslee and Lone (1995) and Blakeslee (1997) utilized EU theory in a dynamic programming model to determine optimal grain marketing decisions in wheat (*Triticum aestivum* L.) production. Woodward, Wui, and Green (2005) also employed EU theory as part of a dynamic programming (DP) model to determine the optimal total allowable catch for large-scale fisheries in the Gulf of Mexico. Krautkraemer, van Kooten, and Young (1992) include both EU theory and safety-first formulations in their stochastic DP analysis of flexcropping in wheat-fallow rotation. Their results are similar between the safety-first formulation and EU decision model. They conclude that the type of problem being investigated should influence how to incorporate risk preferences into stochastic DP models. van Kooten, Young, and Krautkraemer (1997) utilized the safety-first objective function (Kataoka, 1963) in their DP model to identify the optimal flexible cropping plan for spring barley (*Hordeum vulgare* L.).

Choosing to periodically fallow outside of a rotation (where the decision to fallow depends on factors such as expected price) is commonly referred to as flex-cropping in the literature (Novak et al., 1994). There is considerable research investigating the economics of flex-cropping, such as systems including spring wheat (*Triticum aestivum* L.) and fallow in the Northern Great Plains (DeVuyst and Halvorson, 2004; Saseendran et al., 2013; Taylor and Novak, 1992; Williams et al., 2010). Much of the research on cropping systems with cotton, peanut, and fallow in the U.S. is related to integrated crop-livestock systems (Acosta-Martínez, Zobeck, and Allen, 2004; Russelle, Entz, and Franzluebbers, 2007; Zhao, Wright, and Marois, 2009). In Australia, researchers have investigated the use of fallow in rotation with cotton (Walker et al., 2005). Based on a literature review, a stochastic DP analysis has not been applied to a flex-cropping system including cotton, peanuts, and fallow.

While risk preferences have been incorporated into stochastic DP models, a literature review did not uncover any applications of Telser's (1956) safety-first constraint in stochastic DP analysis of cropping decisions of cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.), including fallowing as a decision option. The objective of this study is to incorporate a safety-first constraint into the DP model structure from Chapter 2 to determine the optimal crop rotation for a peanut and cotton producer in Alabama under alternative land tenure arrangements assuming a producer can choose to leave land fallow.

3.2 Dynamic Programming Model

The DP model outlined in Chapter 2 was augmented with a Telser's safety-first constraint on annual returns and addition of fallow as a state variable. The objective of the crop rotation model was to maximize the expected present value of returns above variable costs over a multi-year planning horizon subject to previous cotton and fallow acreage, Markovian cotton and peanut prices, and a safety-first constraint. The safety-first constraint divides the cropping decisions into two groups, and rules out certain cropping decisions. The first group includes cropping decisions where the probability of net returns less than or equal to the disaster income level is greater than an acceptable level of risk. The second group includes cropping decisions where the probability of net returns less than or equal to the disaster income level is less than or equal to an acceptable level of risk. The second group may enter the optimal solution.

The Bellman's DP recursive equation is specified as:

$$V_t(PPNT_t, PCOT_t, L_{t-1}, LA_{t-1}) = \max_{x_t, a_t, n_t, f_t}\{E[R_t(PPNT_t, PCOT_t, L_{t-1}, LA_{t-1}, x_t, a_t, n_t, f_t) + \beta V_{t+1}(PPNT_{t+1}, PCOT_{t+1}, L_t, LA_t)]\}, \qquad (3.1)$$

Subject to the safety-first constraint:

$$P_r(R_t(\bullet) \leq d | x_t, a_t, n_t, f_t) \leq \alpha \qquad (3.2)$$

Where

$V_t(\bullet)$ = maximum expected present value of returns over variable and land tenure costs from crop year *t* through the end of the planning horizon *T*;

$PPNT_t$ = market price of peanut in crop year *t*;

$PCOT_t$ = market price of cotton lint in crop year *t*;

L_{t-1} = cotton acreage state variable in crop year *t - 1*;

LA_{t-1} = fallow acreage state variable in crop year *t - 1*;

x_t= cotton acreage decision variable in crop year *t*;

a_t= fallow acreage decision variable in crop year *t*;

n_t = a binary variable indicating the use of a nematicide in crop year *t*;

f_t = a binary variable indicating the use of a fungicide if the crop is peanut in crop year *t*;

$R_t(\bullet)$ = the function showing annual returns over variable production costs in crop year *t*;

β = the annual discount factor;

E = expectation operator, with the expectation taken with respect to the set of stochastic variables in the state transition equation;

P_r= probability distribution;

d = disaster level of income; and

α = risk aversion coefficient.

The discount factor was assumed to be 0.952 (4.8% real interest rate). The disaster level of income was assumed to be the cost of the land remaining fallow (rental cost). The risk aversion coefficient was initially set equal to 0.10. Due to the curse of dimensionality, the addition of the fallow acreage state variable (LA_{t-1}) significantly increases the computational time required to solve the optimization model.

3.3 Empirical Model

The empirical model utilized in Chapter 3 is similar to the model developed in Chapter 2. The major differences are the inclusion of fallow as a state variable and decision variable, and the use of Telser's (1956) safety-first constraint to incorporate risk preferences in the DP model. This section outlines the similarities and differences between Chapter 2 and Chapter 3.

3.3.1 Experimental methods

The experimental methods used in analysis are the same as those utilized in Chapter 2. A detailed description of the experiment, treatment definitions, and summary statistics are found in Chapter 2.

3.3.2 Peanut and cotton yield response functions

The estimated yield response functions for peanut and cotton lint are given in Table 3.1, and were estimated using data from the R-1 experiment from 1980 to 2002. Additional discussion is found in Chapter 2. While the statistical formulations of the two yield response functions were the same as in Chapter 2, binary variables for fallow production were added to the mathematical specifications to adjust cotton and peanut yields following fallow. The yield response functions were mathematically specified as:

$$COTY_t = \gamma_0 + (\gamma_1 * L_{t-1}) * \theta_c + \gamma_2 * n_t + \gamma_3 * AVGCY_t + \varepsilon_{2,t} \tag{3.3}$$

$$PNY_t = \delta_0 + (\delta_1 * L_{t-1}) * \theta_p + \delta_2 * n_t + \delta_3 * f_t + \delta_4 * AVGPY_t + \varepsilon_{3,t}, \tag{3.4}$$

where: L_{t-1} is a binary variable for prior year crop in *t-1* (1 = cotton and 0 = peanut); θ_c is the binary variable for fallow in a cotton rotation (1 = cotton yield following fallow equal to cotton yield following cotton, 0 = cotton yield following fallow is equal to cotton yield following peanut); θ_p is the binary variable for fallow in a peanut rotation (1 = peanut yield following fallow equal to cotton yield following peanut, 0 = peanut yield following fallow is equal to peanut yield following peanut); n_t is a binary variable for nematicide treatment (1 = received nematicide treatment, 0 = otherwise) in time *t*; f_t is a binary variable for fungicide treatment for peanut (1 = received fungicide treatment, 0 = otherwise) in time *t*; $AVGCY_t$ and $AVGPY_t$ are average county cotton lint and peanut yields, respectively, in Henry County, Alabama in time *t*; γ and δ are estimated coefficients; and $\varepsilon_{x,t}$ are random error terms for Equations (3.3) and (3.4).

Table 3.1. Crop yield equations

Eq. No.	Crop	Stochastic equation
3.3	Cotton	$COTY_t^1 = 430.929 - (133.129L_{t-1})\theta_c + 195.133n_t + 0.595AVGCY_t + \varepsilon_{3.2,t}$ $\sigma^2 = 253.39$
3.4	Peanut	$PNTY_t = 1799.61 + (479.51L_{t-1})\theta_p + 422.27n_t + 597.02f_t + 0.187AVGPY_t + \varepsilon_{3.3,t}$ $\sigma = 696.69$

[1] L_{t-1} is a binary variable for prior year crop in *t-1* (1 = cotton and 0 = peanut); θ_c is the binary variable for fallow in a cotton rotation (1 = cotton yield following fallow equal to cotton yield following cotton, 0 = cotton yield following fallow is equal to cotton yield following peanut); θ_p is the binary variable for fallow in a peanut rotation (1 = peanut yield following fallow equal to cotton yield following peanut, 0 = peanut yield following fallow is equal to peanut yield following peanut); n_t is a binary variable for nematicide treatment (1 = received nematicide treatment, 0 = otherwise); f_t is a binary variable for fungicide treatment for peanut (1 = received fungicide treatment, 0 = otherwise); $AVGCY_t$ and $AVGPY_t$ are average county cotton lint and peanut yields, respectively, in Henry County, Alabama

[2] σ is the estimated standard deviation (root mean squared error) of the additive random error term.

When including fallow as an option in the recursive equation, fallow had to be given consideration in the crop yield equations. The manner in which fallow ground is managed influences the yield of the following crop. If the fallow ground is actively managed (i.e., weed control activities during the fallow period), the yield of the subsequent crop will be close to those of a crop grown in rotation. However, if the fallow ground is not actively managed (i.e., weeds are terminated prior to planting subsequent crop), the weeds may harbor pests that will be detrimental to the following crop, producing yields similar to yields of crops produced as part of a monoculture. The initial assumption is that the fallow ground is not actively managed and burndown occurs as part of normal production activities.

3.3.3 State Variables and Transition Probabilities

As in Chapter 2, the cotton lint and peanut price state variables are stochastic. There are two prior landuse variables (percent cotton acreage and percent fallow acreage) which are deterministic. The price state variables are unchanged from Chapter 2, including the state transition equations. The statistically estimated equations are shown in Table 3.2. The deterministic landuse state variables (L_t and LA_t) were discretized into 11 states each from 0 to 1 by increments of 0.10. Since the sum of the deterministic landuse state variables cannot exceed one, the total states were 6600.

Table 3.2. Markovian price relationships for cotton and peanut from 1982 to 2012

Eq. No.	Crop	Stochastic equation
3.5	Cotton	$\log(\mathrm{COTP_t}) = -0.093 + 0.681\log(\mathrm{COTP_{t-1}}) + \varepsilon_{3.x,t}$ $\sigma = 0.219$
3.6	Peanut	$\log(\mathrm{PNP_t}) = -0.112 + 0.908\log(\mathrm{PNP_{t-1}}) + \varepsilon_{3.x,t}$ $\sigma = 0.219$

[1] In the estimate equations above, σ is the estimated standard deviation (root mean squared error) of the additive random error term

The stochastic state transition equations for peanut and cotton lint prices are represented as a matrix of Markovian transition probabilities. Following Chapter 2, the elements of the full Markovian transition matrix are given by:

$$p = Pr(PPN_t, PCT_t | PPN_{t-1}, PCT_{t-1}) = Pr(PPN_t | PPN_{t-1}) * \Pr(PCT_t | PCT_{t-1}), \quad (3.7)$$

where p is the full Markovian transition matrix. As in Chapter 2, the prior landuse transitions are deterministic. Transition probabilities, as well as unconditional price probabilities, remained unchanged from Chapter 2. Equation (3.1) can be rewritten in Markovian DP notation as follows:

$$V_t(PPNT_t, PCOT_t, L_{t-1}, LA_{t-1}) =$$

$$\max_{x_t, a_t, n_t, f_t}\{R_t(PPNT_t, PCOT_t, L_{t-1}, LA_{t-1}, x_t, a_t, n_t, f_t) +$$

$$\beta \sum_{ppnt_{t+1}} \sum_{pcot_{t+1}} \sum_{L_t} [V_{t+1}(PPNT_{t+1}, PCOT_{t+1}, L_t, LA_{t-1}) * Pr(PPN_{t+1}|PPN_t) *$$

$$\Pr(PCT_{t+1}|PCT_t)]\}. \tag{3.8}$$

3.3.4 Decision Variables

The initial decision variables for the model were proportion of cotton acreage (x_t), proportion of fallow acreage (a_t), adoption of nematicide (n_t), and adoption of fungicide (f_t). As stated earlier, based on yield response functions, it was assumed that producers always choose to adopt nematicide and fungicide treatments; therefore x_t and a_t were the decision variables in the DP model. The two acreage decision variables were discretized to coincide with the prior landuse state variables. Decisions ranged from 0 to 1 in increments of 0.10 for each acreage decision variable. A producer must decide what proportion of acreage to allocate to cotton production, peanut production, and/or fallow. As with the state variables, the sum of the allocated acres must be less than or equal to one; therefore, there were a total of 66 decisions (as shown in Appendix A).

3.3.5 Other input data

Variable and fixed costs (excluding land tenure costs) for cotton and peanut production were included in $R_t(\bullet)$ and in the safety-first constraint. Production costs are discussed in detail in Chapter 2. Table 3.3 provides a summary of the variable and fixed costs associated with cotton and peanut production assuming cotton lint yield of 892 lbs ac^{-1} and peanut yield of 3617 lbs ac^{-1}.

Table 3.3. Summary of per acre production costs for cotton and peanut in 2012 dollars assuming average experimental yield and adoption of nematicide and fungicide treatments.

Cost Components	Cotton	Peanut
	US$ ac^{-1}	
Total Variable Costs	$408.87	$533.28
Total Yield Varying Costs	$103.54	$55.36
Total Fixed Costs	$161.43	$174.10
Total Costs Excluding Land	$673.84	$762.74

[1] Assumes cotton lint yield of 892 lbs ac^{-1} and peanut yield of 3617 lbs ac^{-1}

3.3.6 Estimating economic return

The annual economic return equation is defined as:

$$R_t = [\{((PCOT_t - vycot) * COTY_t) - vcot - lt\} * (CC_t + PC_t + FC_t)] + [\{((PPNT_t - vypnt) * PNTY_t) - vpnt - lt\} * (PP_t + CP_t + FP_t)]+)] + [\{-lt\} * (FF_t + CF_t + PF_t)] \qquad (3.9)$$

where $PCOT_t$ and $PPNT_t$ are price of cotton and peanut in US$ lb^{-1}, respectively; $COTY_t$ and $PNTY_t$ are yields of cotton and peanut in lbs ac^{-1} (which depends on previous crop and production methods), respectively; $vycot$ and *vypnt* are variable costs of producing cotton and peanut dependent on yield; $vcot$ and *vpnt* are variable and fixed costs of cotton and peanut not dependent on yield; lt is cost of land tenure; and $CC_t, PC_t, FC_t, PP_t, CP_t, FP_t, FF_t, CF_t,$ and PF_t are the portion of land planted to cotton following cotton, cotton following peanut, cotton following fallow, peanut following peanut, peanut following cotton, peanut following fallow, fallow following fallow, fallow following cotton, and fallow following peanut, respectively.

The economic return is affected by the cotton lint and peanut yield and prices, land tenure arrangements, total variable and fixed costs, and the portion of land planted to cotton, peanut, and/or fallow. As in Chapter 2, the expected cotton and peanut prices are assumed to be the “from” price since producers routinely contract their cotton and peanut production prior to planting.

3.3.7 Land tenure arrangement scenarios

Considering the results of Chapter 2, three land tenure arrangement scenarios were considered: CR, FCRP, and FCRR. The initial assumptions are displayed in Table 3.4.

Table 3.4. Land tenure assumptions

Variable	Value	Unit
Cash Rent	50.00	US\$ ac^{-1}
Base Rent	50.00	US\$ ac^{-1}
Base Cotton Price	0.73	US\$ lb^{-1}
Base Peanut Price	0.26	US\$ lb^{-1}
Base Cotton Yield	892	lb ac^{-1}
Base Peanut Yield	3617	lb ac^{-1}
Base Cotton Revenue	651.16	US\$ ac^{-1}
Base Peanut Revenue	940.42	US\$ ac^{-1}
Minimum Rent	25.00	US\$ ac^{-1}
Maximum Rent	75.00	US\$ ac^{-1}

Using the percent change method to calculate the flexible cash rent, the following equations are used to calculate flexible cash rents based on revenue, respectively:

$$FCRP = BCR + \left(BCR * \left(\frac{FP-EP}{EP}\right)\right) \tag{3.10}$$

$$FCRR = BCR + \left(BCR * \left(\frac{FR-ER}{ER}\right)\right) \tag{3.11}$$

where *BCR* is base cash rent; *FP* and *FR* are final price and final revenue, respectively; and *EP* and *ER* are expected price and expected revenue, respectively. Flexible cash rents based on yield was not included since FCRR accounts for both price and yield risk, and yield is not stochastic.

The base rent was set equal to the cash rent in the base scenario and the minimum and maximum rents were set at 25 US$ ac^{-1} below and above the base rent. Expected revenue for each crop was the expected price multiplied by the expected yields for cotton lint and peanut. Expected prices for cotton lint and peanut were the average price received by producers from 2008 to 2012. Expected yields were the average yields from the experimental data assuming adoption of nematicide and fungicide treatments.

Cash rent and flexible cash rent costs were included as variable costs. It was assumed that producers made an initial rent payment to the landlord equal to the cash rent or minimum rent (depending on scenario) prior to planting, which was included in the calculation of interest on operating capital. Rental payments were also included in the calculation of general overhead and management.

While there are qualitative costs associated with fallowing land, such as potential termination of a lease by the landowners, the cost of fallowing land was assumed to be equal to the cash rent in the CR scenario and the minimum base rent in the FCRP and FCRR scenarios. In each scenario, the appropriate rent was used to calculate the operating interest expense. For example, when considering FCRR with fallow land, the actual revenue would be 0 US$ ac^{-1}, and the FCRR would be -25.70 US$ ac^{-1} (minimum base rent plus operating interest). It was assumed that rental agreements were not subject to termination over the period of analysis.

3.3.8 Safety-first constraint

For the purposes of this analysis, the disaster level of income was defined as the cost of fallowing land. The acceptable level of risk was initially set at 0.10 and was increased to 0.25 and 1 for sensitivity analysis. The safety-first constraint was defined (for the purposes of this analysis) as the probability of annual net returns ($R_t(\bullet)$) less than or equal to the cost of fallowing being less than or equal to 0.10 (acceptable level of risk).

3.4 Results and Discussion

Due to the large number of states in the DP model, the following paragraphs are focused on a subset of the optimal solution. The complete optimal solution for the CR scenario is found in Appendix C.[13] The optimal decision rule in the DP model converged by at least the sixth stage (t = 6) for each scenario. The decision rule is applicable to years one through six, assuming a planning horizon of 25 years. For longer planning horizons, the decision ruled holds until the current time period is within five years of the end of the planning horizon.

Tables 3.5, 3.6, and 3.7 present the optimal decision rule (or matrix) for a subset of peanut and cotton prices for 100% peanut, 100% fallow, 100% cotton, and 20% cotton/80% cotton for CR, FCRP, and FCRR, respectively. The panels in each table are for a different proportion of peanut, cotton, and/or fallow acreage. In each panel, the brown cells are 100% fallow, the green cells are 100% peanut, and the blue cells are 100% cotton. The white cells are for combinations of cotton, peanut, and/or fallow (i.e. 20C/80P is 20% cotton and 80% peanut; 40C/40P/20F is 40% cotton, 40% peanut, and 20% fallow).

Assuming prior year landuse is 100% peanut, and with price of cotton at 0.80 US\$ lb^{-1} and price of peanut at 0.30 US\$ lb^{-1}, producers who CR should plant 100% cotton (Table 3.5). As the price of peanut increased (holding the price of cotton constant) producers should plant continuous peanut and as the price of peanut decreases, producers

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[13] A full decision rule is available from the author on request.

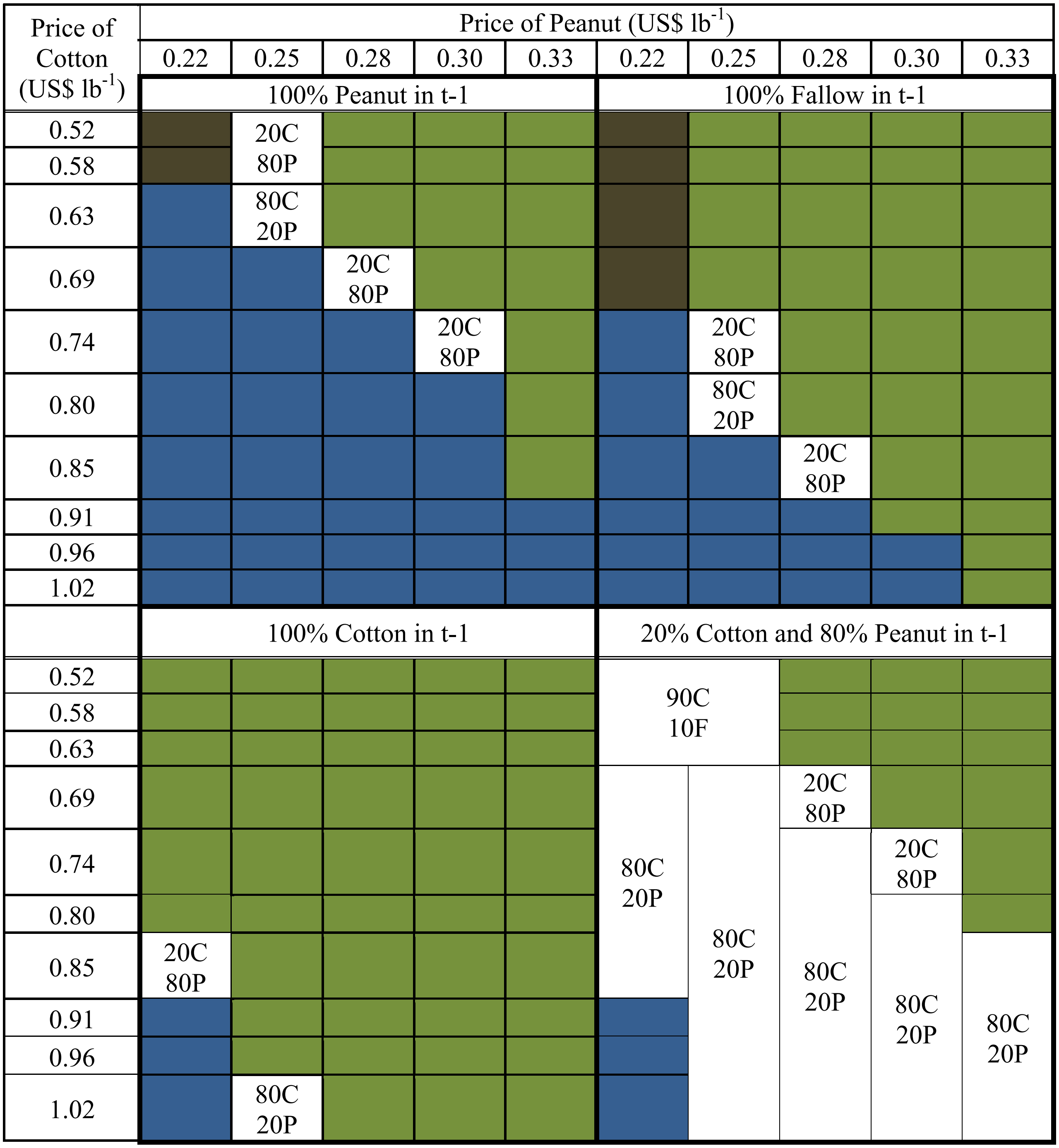
should plant cotton following peanut. This was true except when expected prices for peanut and cotton were low, with fallow land or a combination of cotton and peanut becoming the optimal solution. If the prior year landuse was 100% cotton, the optimal solution was 100% peanut except in cases of high cotton prices and low peanut prices. For producers who cash rent flexed on revenue (FCRR), the results were similar to the CR scenario, with few exceptions (Table 3.7). When cotton prices and peanut prices were low and the prior year landuse was 100% peanut, the optimal solution was to fallow 100% of the land, even as cotton prices reached 0.58 US$ lb^{-1}. Similarly, when cotton prices and peanut prices were low and the prior year landuse was 100% fallow, the optimal solution was to continue to fallow 100% of the land until cotton prices reached 0.74 US$ lb^{-1} (brown cells in Table 3.7). For producers, fallowing serves as a proxy for other crop choices, such including corn in rotation, or refraining from renting new land when there are low expected prices. The cash rent flexed on price (FCRP) scenario presented slightly different results. In the FCRP scenario, the optimal solution more heavily favors a mixture of crops (i.e. 80% cotton and 20% peanut) than the FCRR scenario, as shown in Tables 3.5, 3.6, and 3.7. Of the three scenarios, the CR scenario had the most crop rotation decisions included in the optimal solution.

Table 3.5. Optimal decision rule with 100% peanut (P), 100% fallow (F), 100% cotton (C), and 20% C and 80% P in (t-1) for the cash rent scenario (CR)

Price of Cotton (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.22	0.25	0.28	0.30	0.33	0.22	0.25	0.28	0.30	0.33
	100% Peanut in t-1					100% Fallow in t-1				
0.52	🟫	20C 80P	🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.58	80C 20P		🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.63	🟦	80C 20P	🟩	🟩	🟩	20C 80P	🟩	🟩	🟩	🟩
0.69	🟦	🟦	20C 80P	🟩	🟩	80C 20P	20C 80P	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟩	🟩	🟦		🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟩	🟦	80C 20P	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	80C 20P	🟦	🟦	20C 80P	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	20C 80P
	100% Cotton in t-1					20% Cotton and 80% Peanut in t-1				
0.52	🟩	🟩	🟩	🟩	🟩	90C 10F		🟩	🟩	🟩
0.58	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩
0.63	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩
0.69	🟩	🟩	🟩	🟩	🟩	80C 20P	80C 20P	20C 80P	🟩	🟩
0.74	🟩	🟩	🟩	🟩	🟩			80C 20P	20C 80P	🟩
0.80	20C 80P	🟩	🟩	🟩	🟩				80C 20P	🟩
0.85		🟩	🟩	🟩	🟩					80C 20P
0.91	🟦	🟩	🟩	🟩	🟩	🟦				
0.96	🟦	20C 80P	🟩	🟩	🟩	🟦				
1.02	🟦	🟦	🟩	🟩	🟩	🟦	🟦			

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres, percent of P acres, and percent of fallow (F) acres. For example, 90C/10P is 90% Cotton and 10% Peanut.

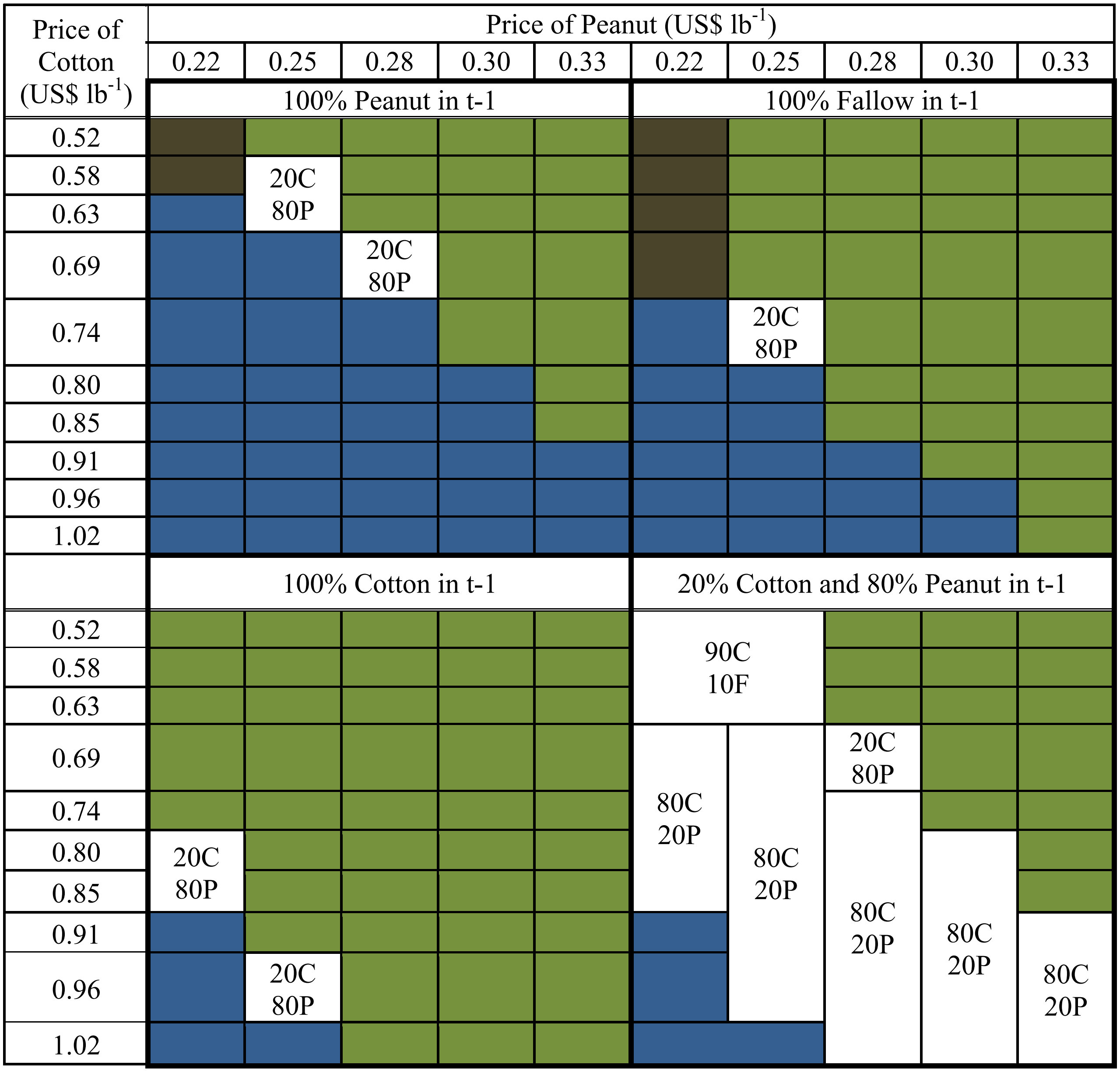
Table 3.6. . Optimal decision rule with 100% peanut (P), 100% fallow (F), 100% cotton (C), and 20% C and 80% P in (t-1) for the cash rent flexed on price scenario (FCRP)



Price of Cotton (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.22	0.25	0.28	0.30	0.33	0.22	0.25	0.28	0.30	0.33
	100% Peanut in t-1					100% Fallow in t-1				
0.52	🟫	20C 80P	🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.58	🟫		🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.63	🟦	80C 20P	🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.69	🟦	🟦	20C 80P	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	20C 80P	🟩	🟦	20C 80P	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟩	🟦	80C 20P	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟩	🟦	🟦	20C 80P	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
	100% Cotton in t-1					20% Cotton and 80% Peanut in t-1				
0.52	🟩	🟩	🟩	🟩	🟩	90C 10F		🟩	🟩	🟩
0.58	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩
0.63	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩
0.69	🟩	🟩	🟩	🟩	🟩	80C 20P	80C 20P	20C 80P	🟩	🟩
0.74	🟩	🟩	🟩	🟩	🟩			80C 20P	20C 80P	🟩
0.80	🟩	🟩	🟩	🟩	🟩				80C 20P	🟩
0.85	20C 80P	🟩	🟩	🟩	🟩					80C 20P
0.91	🟦	🟩	🟩	🟩	🟩	🟦				
0.96	🟦	🟩	🟩	🟩	🟩	🟦				
1.02	🟦	80C 20P	🟩	🟩	🟩	🟦				

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres, percent of P acres, and percent of fallow (F) acres. For example, 90C/10P is 90% Cotton and 10% Peanut.

Table 3.7. Optimal decision rule with 100% peanut (P), 100% fallow (F), 100% cotton (C), and 20% C and 80% P in (t-1) for the cash rent flexed on revenue scenario (FCRR)



Price of Cotton (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.22	0.25	0.28	0.30	0.33	0.22	0.25	0.28	0.30	0.33
	100% Peanut in t-1					100% Fallow in t-1				
0.52	🟫	🟩	🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.58	🟫	20C 80P	🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.63	🟦		🟩	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.69	🟦	🟦	20C 80P	🟩	🟩	🟫	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟩	🟩	🟦	20C 80P	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩
	100% Cotton in t-1					20% Cotton and 80% Peanut in t-1				
0.52	🟩	🟩	🟩	🟩	🟩	90C 10F		🟩	🟩	🟩
0.58	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩
0.63	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩
0.69	🟩	🟩	🟩	🟩	🟩	80C 20P	80C 20P	20C 80P	🟩	🟩
0.74	🟩	🟩	🟩	🟩	🟩			80C 20P	🟩	🟩
0.80	20C 80P	🟩	🟩	🟩	🟩				80C 20P	🟩
0.85		🟩	🟩	🟩	🟩					🟩
0.91	🟦	🟩	🟩	🟩	🟩	🟦				80C 20P
0.96	🟦	20C 80P	🟩	🟩	🟩	🟦				
1.02	🟦	🟦	🟩	🟩	🟩	🟦				

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres, percent of P acres, and percent of fallow (F) acres. For example, 90C/10P is 90% Cotton and 10% Peanut.

Considering a prior year landuse of 50% peanut and 50% cotton, producers would choose to remain in a 50/50 rotation under approximately half of the price combinations (Table 3.8, 3.9, and 3.10). The exceptions were combinations of high price peanut and low price cotton and high price cotton and low price peanut. Assuming a cotton lint price of 0.80 US$ lb^{-1} and a peanut price of 0.30 US$ lb^{-1}, producers maintained a 50/50 peanut/cotton rotation in all three scenarios. As the price of peanut increased (relative to the price of cotton), the optimal strategy was to grow 100% peanut. As the price of cotton increases (relative to the price of peanut) the optimal strategy was to continue a 50/50 peanut/cotton rotation. For most price comparisons, regardless of scenario, the optimal solution contained a crop mix. With few exceptions, the results were similar regardless of land tenure arrangement.

There were optimal solutions for 16 price combinations reported in Tables 3.6 – 3.10 that were exactly the same regardless of scenarios and prior year landuse. The optimal solution for cotton prices greater than or equal to 0.91 US$ lb^{-1} and a peanut price of 0.22 US$ lb^{-1} was always 100% cotton, regardless of the prior year crop. The same was true for the following price combinations: cotton prices less than or equal to 0.63 US$ lb^{-1} and peanut prices greater than or equal to 0.28 US$ lb^{-1}; cotton price of 0.69 US$ lb^{-1} and peanut prices greater than or equal to 0.30 US$ lb^{-1}; cotton price of 0.74 US$ lb^{-1} and 0.80 US$ lb^{-1} and a peanut price of 0.33 US$ lb^{-1}.

Over a five-year period, assuming prices stay constant at 0.80 US$ lb^{-1} for cotton lint and 0.30 US$ lb^{-1} for peanut and the producer grew 100% peanut in stage t-1, the optimal rotation was (as shown in Table 3.5):

$100\%\ peanuts_{t-1}\colon 100\%\ cotton_{t}\colon 100\%\ peanuts_{t+1}\colon$

$100\%\ cotton_{t+2}\colon 100\%\ peanuts_{t+3}\colon 100\%\ cotton_{t+4}$, where “:” is the divider between years in rotation. This was the optimal strategy for all land tenure arrangements. If peanut prices remain constant, a decrease in cotton prices would make a continuous peanut rotation optimal until cotton prices increased or peanut prices decreased from 0.30 US$ lb^{-1}. If a producer grew 50% peanut and 50% cotton in stage t-1 (assuming 0.80 US$ lb^{-1} for cotton lint and 0.30 US$ lb^{-1} for peanut), the optimal rotation was (as shown in Table 3.8): $50\%\ peanuts_{t-1}\ and\ 50\%\ cotton_{t-1}$: $50\%\ peanuts_{t}\ and\ 50\%\ cotton_{t}$: $50\%\ peanuts_{t+1}\ and\ 50\%\ cotton_{t+1}$: $50\%\ peanuts_{t+2}\ and\ 50\%\ cotton_{t+2}$: $50\%\ peanuts_{t+3}\ and\ 50\%\ cotton_{t+3}$: $50\%\ peanuts_{t+4}\ and\ 50\%\ cotton_{t+4}$. A decrease in the price of cotton without a decrease in the price of peanut, allowed for a continuous peanut rotation to become optimal until cotton price increased and/or peanut price decreased. For the results displayed in Tables 3.5 – 3.10, assuming 0.80 US$ lb^{-1} for cotton lint and 0.30 US$ lb^{-1} for peanut, the optimal solution was always a crop rotation of cotton and peanuts.

Table 3.8. Optimal decision rule with 50% peanut (P) and 50% cotton (C), 60% C, 30% P and 10% fallow (F), 30% C and 70% P, and 70% C and 30% P in (t-1) for the cash rent (CR)

Price of Cotton (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.22	0.25	0.28	0.30	0.33	0.22	0.25	0.28	0.30	0.33
	50% C and 50% P in t-1					60% C, 30% P, and 10% F in t-1				
0.52	60C 30P 10F	60C 30P 10F	🟩	🟩	🟩	40C 40P 20F	20C 80P	🟩	🟩	🟩
0.58		20C 80P	🟩	🟩	🟩			🟩	🟩	🟩
0.63			🟩	🟩	🟩	30C 70P		🟩	🟩	🟩
0.69	50C 50P	50C 50P	20C 80P	🟩	🟩		30C 70P	20C 80P	🟩	🟩
0.74			50C 50P	🟩	🟩	40C 60P		30C 70P	🟩	🟩
0.80				50C 50P	🟩		40C 60P		30C 70P	🟩
0.85	80C 20P				50C 50P	80C 20P				30C 70P
0.91	🟦					🟦		40C 60P		
0.96	🟦					🟦			40C 60P	
1.02	🟦	🟦				🟦	🟦			
	30% C and 70% P in t-1					70% C and 30% P in t-1				
0.52	80C 10P 10F		🟩	🟩	🟩	40C 50P 10F	20C 80P	🟩	🟩	🟩
0.58			🟩	🟩	🟩			🟩	🟩	🟩
0.63			🟩	🟩	🟩	30C 70P		🟩	🟩	🟩
0.69	70C 30P	70C 30P	20C 80P	🟩	🟩		30C 70P	20C 80P	🟩	🟩
0.74			70C 30P	🟩	🟩			30C 70P	🟩	🟩
0.80				70C 30P	🟩				30C 70P	🟩
0.85	80C 20P				70C 30P	80C 20P				30C 70P
0.91	🟦					🟦				
0.96	🟦					🟦				
1.02	🟦	🟦				🟦	🟦			

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres, percent of P acres, and percent of fallow (F) acres. For example, 90C/10P is 90% Cotton and 10% Peanut.

Table 3.9. Optimal decision rule with 50% peanut (P) and 50% cotton (C), 60% C, 30% P and 10% fallow (F), 30% C and 70% P, and 70% C and 30% P in (t-1) for the cash rent flexed on price (FCRP)

Price of Cotton (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.22	0.25	0.28	0.30	0.33	0.22	0.25	0.28	0.30	0.33
	50% C and 50% P in t-1					60% C, 30% P, and 10% F in t-1				
0.52	60C 30P 10F	60C 30P 10F	🟩	🟩	🟩	40C 40P 20F	20C 80P	🟩	🟩	🟩
0.58		20C 80P	🟩	🟩	🟩			🟩	🟩	🟩
0.63		50C 50P	🟩	🟩	🟩	30C 60P 10F	30C 70P	🟩	🟩	🟩
0.69	50C 50P		20C 80P	🟩	🟩	30C 70P		20C 80P	🟩	🟩
0.74			50C 50P	20C 80P	🟩	40C 60P		30C 70P	20C 80P	🟩
0.80				50C 50P	🟩		40C 60P		30C 70P	🟩
0.85					50C 50P					30C 70P
0.91	🟦					🟦		40C 60P		
0.96	🟦					🟦			40C 60P	
1.02	🟦	80C 20P				🟦	80C 20P			
	30% C and 70% P in t-1					70% C and 30% P in t-1				
0.52	80C 10P 10F	80C 10P 10F	🟩	🟩	🟩	40C 50P 10F	20C 80P	🟩	🟩	🟩
0.58			🟩	🟩	🟩			🟩	🟩	🟩
0.63		70C 30P	🟩	🟩	🟩	30C 70P	30C 70P	🟩	🟩	🟩
0.69	70C 30P		20C 80P	🟩	🟩			20C 80P	🟩	🟩
0.74			70C 30P	20C 80P	🟩			30C 70P	20C 80P	🟩
0.80				70C 30P	🟩				30C 70P	🟩
0.85					70C 30P					30C 70P
0.91	🟦					🟦				
0.96	🟦					🟦				
1.02	🟦	80C 20P				🟦	80C 20P			

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres, percent of P acres, and percent of fallow (F) acres. For example, 90C/10P is 90% Cotton and 10% Peanut.

Table 3.10. Optimal decision rule with 50% peanut (P) and 50% cotton (C), 60% C, 30% P and 10% fallow (F), 30% C and 70% P, and 70% C and 30% P in (t-1) for the cash rent flexed on price (FCRR)

Price of Cotton (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.22	0.25	0.28	0.30	0.33	0.22	0.25	0.28	0.30	0.33
	50% C and 50% P in t-1					60% C, 30% P, and 10% F in t-1				
0.52	60C 30P 10F	60C 30P 10F	🟩	🟩	🟩	40C 40P 20F	🟩	🟩	🟩	🟩
0.58		20C 80P	🟩	🟩	🟩		20C 80P	🟩	🟩	🟩
0.63			🟩	🟩	🟩	30C 60P 10F		🟩	🟩	🟩
0.69	50C 50P		20C 80P	🟩	🟩	30C 70P	30C 70P	20C 80P	🟩	🟩
0.74		50C 50P	50C 50P	🟩	🟩	40C 60P		30C 70P	🟩	🟩
0.80				50C 50P	🟩		40C 60P		30C 70P	🟩
0.85	80C 20P				🟩					🟩
0.91	🟦				50C 50P	🟦		40C 60P		30C 70P
0.96	🟦					🟦			40C 60P	
1.02	🟦	🟦				🟦	🟦			
	30% C and 70% P in t-1					70% C and 30% P in t-1				
0.52	80C 10P 10F	80C 10P 10F	🟩	🟩	🟩	40C 50P 10F	🟩	🟩	🟩	🟩
0.58			🟩	🟩	🟩		20C 80P	🟩	🟩	🟩
0.63		20C 80P	🟩	🟩	🟩	30C 70P		🟩	🟩	🟩
0.69	70C 30P	70C 30P	20C 80P	🟩	🟩		30C 70P	20C 80P	🟩	🟩
0.74			70C 30P	🟩	🟩			30C 70P	🟩	🟩
0.80				70C 30P	🟩				30C 70P	🟩
0.85	80C 20P				🟩					🟩
0.91	🟦				70C 30P	🟦				30C 70P
0.96	🟦					🟦				
1.02	🟦	🟦				🟦	🟦			

Note: The green area represents 100% Peanut (P). The blue area represents 100% Cotton (C). The white areas are interpreted as the percent of C acres, percent of P acres, and percent of fallow (F) acres. For example, 90C/10P is 90% Cotton and 10% Peanut.

As in Chapter 2, the yield increase due to a rotation, ratio of cotton price to peanut price, along with production costs, drove the rotation decision. However, the safety-first constraint was an important factor in the rotation decision, especially at low commodity prices. In Tables 3.5 – 3.7, if the price of peanut is 0.22 US\$ lb^{-1}, cotton price is 0.52 US\$ lb^{-1}, and the prior land use was 100% peanut, the optimal decision was 100% fallow and would remain in fallow until peanut prices increased or cotton priced increased above 0.58 US\$ lb^{-1} in the CR scenario. For FCRP and FCRR, the cotton price would have to increase to above 0.69 US\$ lb^{-1} to move back into a peanut/cotton rotation, assuming peanut prices remain low. Fallow was also included in the optimal solution when prior landuse was 50% peanut and 50% cotton; however, 100% fallow was not in the optimal solution (Tables 3.8 – 3.10).

It was interesting to note that when prior year landuse was 100% cotton, the optimal solution was 100% peanut regardless of peanut price or land tenure scenario, except in cases of high cotton prices. Net returns for 100% peanut following 100% cotton were greater than net returns for the other decisions, even at low commodity prices; however, net returns for 100% cotton following 100% peanut were less than the cost to leave the land fallow (as well as the other decision options) at low commodity prices. Although there are a number of reasons a producer would choose to fallow land, in this analysis, the decision is based solely on economic return. In reality, environmental constraints, such as adverse weather events, may prevent a producer from planting. Even though cotton and peanut were the only crops included in the analysis, the decision to fallow cropland may represent the opportunity for alternative crops, such as corn or soybeans, to be included in the rotation if the return to the alternative crop exceeds the cost of fallowing and satisfies the safety-first constraint. This is beyond the scope of this analysis but may be considered in future research.

The annualized net returns[14] for the optimal strategy assuming prior landuse of 50% peanut and 50% cotton at 0.74 US$ lb^{-1} cotton lint and 0.28 US$ lb^{-1} peanut for each scenario were calculated from the present value of returns over variable and fixed costs, including land tenure costs. The present value of returns over variable and fixed costs and annualized net returns are displayed in Table 3.11. The scenario with the highest annualized net returns was CR at 270.97 US$ ac^{-1}, followed by FCRR (262.63 US$ ac^{-1}), and FCRP (259.33US$ ac^{-1}). It was interesting to note that over the long-term, a standard CR scenario has higher returns than FCRP and FCRR scenarios. The profitability of the FCRP and FCRR scenarios was dependent on the model assumptions. If base cotton and/or peanut prices were increased, FCRP would decrease, as would FCRR. As the level of risk (α) was increased from 10% there was a slight increase in annualized net returns for all three land tenure scenarios. This indicates that producers were willing to accept lower net returns if production risk was lower.

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[14] Annualized net returns were calculated as the present value of returns over variable and fixed costs divided by 14.3809, which is the uniform series present value over 25 years at an interest rate of 4.8% $[USPV_{4.8,25}]$.

Table 3.11. Present value of returns over variable and fixed costs and annualized net returns by scenario assuming approximate current prices of 0.74 US\$ lb^{-1} cotton lint and 0.26 US\$ lb^{-1} peanut, and assuming previous landuse of 50% peanut and 50% cotton.

	$\alpha = 0.10$		$\alpha = 0.25$	$\alpha = 1$
Scenario	Present value of returns over variable and fixed costs	Annualized net returns	Annualized net returns	Annualized net returns
	US\$ ac^{-1}			
CR	3941.46	270.97	275.28	275.47
FCRP	3772.95	259.33	263.55	263.80
FCRR	3816.17	262.63	266.74	266.88

3.4.1 Limitations

The limitations in Chapter 3 are similar to the limitations outlined in Chapter 2, with two additions. First, changes in the disaster level and acceptable level of risk, as part of the safety-first constraint, may change the optimal outcome of the DP model. Secondly, the model does not consider the termination of a lease due to fallowing or the option for a producer to rent their land to a tenant in periods of low prices. In many cases, a process of developing a DP model and the optimal solution raise more questions than answers. However, due to the curse of dimensionality, addressing all questions in one DP model is unrealistic. Many of the limitations discussed in Chapter 2 and 3 can be addressed in future research with minor adjustments to the DP model.

3.5 Summary and Conclusions

Most agricultural producers would identify themselves as profit maximizers but many also want to reduce the amount of risk they face when making production decisions. This analysis investigated the optimal decision rule associated with producing peanuts and cotton in Alabama. While this type of analysis is useful in answering specific questions, it has the tendency to generate additional research questions. As the number and complexity of research questions grow, the curse of dimensionality becomes a constraint, even with current computing power. Adding the fallowing option to the model increased the complexity of the model and the presentation of the optimal decision rule.

Economic returns were evaluated for each peanut and cotton price combination and previous proportions of cotton and fallow acreage. Adopting a peanut/cotton crop rotation with the option of fallowing with consideration given to the type of land tenure arrangement may be an appropriate risk management option for producers. As shown in Chapter 2, the decision to adopt a rotation instead of monoculture is heavily influenced by expected yield (which is dependent on prior year crop), production costs, and expected prices.

Assuming the price of cotton at 0.80 US\$ lb^{-1} and the price of peanut at 0.30 US\$ lb^{-1}, a cotton/peanut rotation was the optimal solution. As the prices of peanut and cotton decrease, the optimal rotation moved toward a monoculture or fallow. As the level of acceptable risk decreased, producers were willing to accept lower net returns (penalty on risk aversion). The optimal strategy is similar across land tenure arrangements; however, the annualized net returns were slightly different. For the producer, the CR scenario had the highest annualized net returns followed by FCRR and FCRP based on the model assumptions. When producers face low peanut and/or cotton prices, the optimal economic decision may be to avoid cropping during these periods (fallowing) or lower their cost of production.

3.6 References

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Appendix A

Table A.1. DP model decision options for Chapter 2

Decision Index	Proportion of Cotton Acres
1	0.00
2	0.10
3	0.20
4	0.30
5	0.40
6	50C
7	0.60
8	0.70
9	0.80
10	0.90
11	1.00

Table A.2. DP model decision options for Chapter 3

Decision Index	Proportion of Cotton Acres	Proportion of Fallow Acres	Decision Index	Proportion of Cotton Acres	Proportion of Fallow Acres
1	0.00	0.00	34	0.30	0.30
2	0.00	0.10	35	0.30	0.40
3	0.00	0.20	36	0.30	50C
4	0.00	0.30	37	0.30	0.60
5	0.00	0.40	38	0.30	0.70
6	0.00	50C	39	0.40	0.00
7	0.00	0.60	40	0.40	0.10
8	0.00	0.70	41	0.40	0.20
9	0.00	0.80	42	0.40	0.30
10	0.00	0.90	43	0.40	0.40
11	0.00	1.00	44	0.40	50C
12	0.10	0.00	45	0.40	0.60
13	0.10	0.10	46	50C	0.00
14	0.10	0.20	47	50C	0.10
15	0.10	0.30	48	50C	0.20
16	0.10	0.40	49	50C	0.30
17	0.10	50C	50	50C	0.40
18	0.10	0.60	51	50C	50C
19	0.10	0.70	52	0.60	0.00
20	0.10	0.80	53	0.60	0.10
21	0.10	0.90	54	0.60	0.20
22	0.20	0.00	55	0.60	0.30
23	0.20	0.10	56	0.60	0.40
24	0.20	0.20	57	0.70	0.00
25	0.20	0.30	58	0.70	0.10
26	0.20	0.40	59	0.70	0.20
27	0.20	50C	60	0.70	0.30
28	0.20	0.60	61	0.80	0.00
29	0.20	0.70	62	0.80	0.10
30	0.20	0.80	63	0.80	0.20
31	0.30	0.00	64	0.90	0.00
32	0.30	0.10	65	0.90	0.10
33	0.30	0.20	66	1.00	0.00

Appendix B

The following table is the optimal decision for the cash rent (CR) scenario. The green areas represent 100% Peanut (P). The blue areas represent 100% Cotton (C). The white areas are interpreted as the percent of C acres. The percent of P acres is 1 – percent of C acres. For example, 90C is 90% cotton and 10% peanut. Using Table B.1 as an example, the table is interpreted as follows:

- Assuming price of cotton at 0.52 US$ lb^{-1}, price of peanut at 0.19 US$ lb^{-1}, and 0% cotton in t-1, the optimal decision for the CR scenario is 100% cotton or 100% cotton following peanut.
- Assuming price of cotton at 1.02 US$ lb^{-1}, price of peanut at 0.39 US$ lb^{-1}, and 0% cotton in t-1, the optimal decision for the CR scenario is 90% C and 10% P or 90% cotton following peanut and 10% peanut following peanut.
- Assuming price of cotton at 0.52 US$ lb^{-1} , price of peanut between 0.16 US$ lb^{-1} and 0.25 US$ lb^{-1}, and 20% cotton and 80% peanut (20C/80P) in t-1, the optimal decision for the CR scenario is 90% cotton and 10% fallow or 80% cotton following peanut, 10% cotton following cotton and 10% fallow following cotton.

Table B.1. Optimal decision rule in (t-1) for the cash rent (CR) scenario

Cotton lint price (US$ lb^{-1})	Price of Peanut (US$ lb^{-1})									
	0.16	0.19	0.22	0.25	0.28	0.30	0.33	0.36	0.39	0.42
	0% Cotton in t-1									
0.52	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	90C	🟩
	10% Cotton in t-1									
0.52	90C	90C	40C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58			90C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			90C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			90C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				90C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				90C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				90C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					80C	🟩

	20% Cotton in t-1									
0.52	80C	80C	20C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58			80C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			80C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			80C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				80C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				10C	🟩	🟩	🟩
0.91	🟦	🟦	🟦				80C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				80C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					80C	🟩
	30% Cotton in t-1									
0.52	70C	70C	50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	80C		70C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			70C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			70C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				70C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				10C	🟩	🟩	🟩
0.91	🟦	🟦	🟦				70C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				70C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					70C	🟩
	40% Cotton in t-1									
0.52	60C	60C	40C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58			60C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			60C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			60C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				60C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				10C	🟩	🟩	🟩
0.91	🟦	🟦	🟦				60C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				60C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					50C	🟩

	50% Cotton in t-1									
0.52	50C	50C	10C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	80C		50C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			50C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			50C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				50C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				50C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				50C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					50C	🟩
	60% Cotton in t-1									
0.52	40C	40C	40C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	50C			🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			40C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			40C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				40C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				40C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				40C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					20C	🟩
	70% Cotton in t-1									
0.52	30C	30C	20C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	40C		30C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			30C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			30C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				30C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦				30C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				30C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					20C	🟩

	80% Cotton in t-1									
0.52	20C	20C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	50C		20C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			20C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			20C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				20C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				10C	🟩	🟩	🟩
0.91	🟦	🟦	🟦				20C	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				20C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					20C	🟩
	90% Cotton in t-1									
0.52	10C	10C	10C	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	40C			🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦			10C	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦				🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦			10C	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦				10C	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦				10C	🟩	🟩	🟩
0.91	🟦	🟦	🟦					🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦				10C	🟩	🟩
1.02	🟦	🟦	🟦	🟦					🟩	🟩
	100% Cotton in t-1									
0.52	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.58	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.63	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.69	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.74	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.80	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.85	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.91	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩
0.96	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩
1.02	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩

Appendix C

The following tables are the optimal decision rule for the cash rent (CR) scenario. The green areas represent 100% peanut (P). The blue areas represent 100% cotton (C). The brown areas represent 100% fallow (F). The white areas are interpreted as the percent of C acres, percent of P acres, and/or percent of F acres. For example, 80C/10P/10F is 80% cotton, 10% peanut, and 10% fallow.

Using Table C.1 as an example, the tables are interpreted as follows:

- Assuming price of cotton at 0.52 US$ lb^{-1} , price of peanut at 0.25 US$ lb^{-1}, and 100% peanut (100P) in t-1, the optimal decision for the CR scenario is 20% cotton and 80% peanut or 20% cotton following peanut and 80% peanut following peanut.
- Assuming price of cotton at 0.52 US$ lb^{-1} , price of peanut between 0.25 US$ lb^{-1} and 0.42 US$ lb^{-1}, and 100% peanut (100P) in t-1, the optimal decision for the CR scenario is 100% peanut or 100% peanut following peanut.
- Assuming price of cotton at 0.52 US$ lb^{-1} , price of peanut between 0.16 US$ lb^{-1} and 0.25 US$ lb^{-1}, and 20% cotton and 80% peanut (20C/80P) in t-1, the optimal decision for the CR scenario is 90% cotton and 10% fallow or 80% cotton following peanut, 10% cotton following cotton and 10% fallow following cotton.

Table C.1. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.52 US\$ lb^{-1}

FROM STATE	Price of Peanut (US\$ lb^{-1})				
	0.16	0.19	0.22	0.25	0.28 to 0.42
100P	🟫	🟫	🟫	20C/80P	🟩
90P/10F	🟫	🟫	🟫		🟩
80P/20F	🟫	🟫	🟫		🟩
70P/30F	🟫	🟫	🟫		🟩
60P/40F	🟫	🟫	🟫		🟩
50P/50F	🟫	🟫	🟫		🟩
40P/60F	🟫	🟫	🟫		🟩
30P/70F	🟫	🟫	🟫		🟩
20P/80F	🟫	🟫	🟫		🟩
10P/90F	🟫	🟫	🟫	🟩	🟩
100F	🟫	🟫	🟫	🟩	🟩
10C/90P	🟫	🟫	10P/90F	20C/80P	🟩
10C/80P/10F	🟫	🟫			🟩
10C/70P/20F	🟫	🟫			🟩
10C/60P/30F	🟫	🟫			🟩
10C/50P/40F	🟫	🟫			🟩
10C/40P/50F	🟫	🟫			🟩
10C/30P/60F	🟫	🟫			🟩
10C/20P/70F	🟫	🟫			🟩
10C/10P/80F	🟫	🟫		🟩	🟩
10C/90F	🟫	🟫		🟩	🟩
20C/80P	90C/10F				🟩
20C/70P/10F	80C/20F				🟩
20C/60P/20F	70C/30F				🟩
20C/50P/30F	60C/40F			20C/80P	🟩
20C/40P/40F	50C/50F				🟩
20C/30P/50F	🟫	40C/60F			🟩
20C/20P/60F	🟫	30C/70F	20C/80P		🟩
20C/10P/70F	🟫	🟫		🟩	🟩
20C/80F	🟫	🟫		🟩	🟩
30C/70P	80C/20F		80C/10P/10F		🟩
30C/60P/10F	70C/30F		70C/10P/20F		🟩

30C/50P/20F	60C/40F		60C/10P/30F	20C/80P	🟩
30C/40P/30F	50C/50F		50C/10P/40F		🟩
30C/30P/40F	🟫	40C/60F	40C/10P/50F		🟩
30C/20P/50F	🟫	30C/70F	20C/80P		🟩
30C/10P/60F	🟫	🟫	30P/70F	🟩	🟩
30C/70F	🟫	🟫	30P/70F	🟩	🟩
40C/60P	70C/30F		70C/20P/10F		🟩
40C/50P/10F	60C/40F		60C/20P/20F		🟩
40C/40P/20F	50C/50F		50C/20P/30F	20C/80P	🟩
40C/30P/30F	🟫	40C/60F	40C/20P/40F		🟩
40C/20P/40F	🟫	30C/70F	20C/80P		🟩
40C/10P/50F	🟫	🟫	40P/60F	🟩	🟩
40C/60F	🟫	🟫		🟩	🟩
50C/50P	60C/40F		60C/30P/10F		🟩
50C/40P/10F	50C/50F		50C/30P/20F	20C/80P	🟩
50C/30P/20F	🟫	40C/60F	40C/30P/30F		🟩
50C/20P/30F	🟫	30C/70F	20C/80P		🟩
50C/10P/40F	🟫	🟫		🟩	🟩
50C/50F	🟫	🟫	50P/50F	🟩	🟩
60C/40P	50C/50F		50C/40P/10F	20C/80P	🟩
60C/30P/10F	🟫	40C/60F	40C/40P/20F		🟩
60C/20P/20F	🟫	30C/70F	20C/80P		🟩
60C/10P/30F	🟫	🟫		🟩	🟩
60C/40F	🟫	🟫	60P/40F	🟩	🟩
70C/30P	🟫	40C/60F	40C/50P/10F	20C/80P	🟩
70C/20P/10F	🟫	30C/70F	20C/80P		🟩
70C/10P/20F	🟫	🟫		🟩	🟩
70C/30F	🟫	🟫		🟩	🟩
80C/20P	🟫	30C/70F		20C/80P	🟩
80C/10P/10F	🟫	🟫		🟩	🟩
80C/20F	🟫	🟫		🟩	🟩
90C/10P	🟫	🟫	20C/70P/10F	🟩	🟩
90C/10F	🟫	🟫	90P/10F	🟩	🟩
100C	🟫	🟫	🟩	🟩	🟩

Table C.2. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.58 US$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb^{-1})				
	0.16	0.19	0.22	0.25	0.28 to 0.42
100P	🟫	🟫	80C/20P	20C/80P	🟩
90P/10F	🟫	🟫			🟩
80P/20F	🟫	🟫			🟩
70P/30F	🟫	🟫	70C/20P/10F		🟩
60P/40F	🟫	🟫	60C/40F		🟩
50P/50F	🟫	🟫	30C/70P		🟩
40P/60F	🟫	🟫			🟩
30P/70F	🟫	🟫			🟩
20P/80F	🟫	🟫	20C/80P		🟩
10P/90F	🟫	🟫	10C/90F		🟩
100F	🟫	🟫	🟫	🟩	🟩
10C/90P	🟫	🟫	80C/20P	20C/80P	🟩
10C/80P/10F	🟫	🟫			🟩
10C/70P/20F	🟫	🟫	70C/20P/10F		🟩
10C/60P/30F	🟫	🟫	60C/20P/20F		🟩
10C/50P/40F	🟫	🟫	30C/70P		🟩
10C/40P/50F	🟫	🟫			🟩
10C/30P/60F	🟫	🟫			🟩
10C/20P/70F	🟫	🟫	20C/80P		🟩
10C/10P/80F	🟫	🟫	10C/10P/80F		🟩
10C/90F	🟫	🟫	10P/90F	🟩	🟩
20C/80P	90C/10F				🟩
20C/70P/10F	80C/20F				🟩
20C/60P/20F	70C/30F			20C/80P	🟩
20C/50P/30F	60C/40F				🟩
20C/40P/40F	50C/50F				🟩
20C/30P/50F	40C/60F				🟩
20C/20P/60F	🟫	30C/70F	20C/80P		🟩
20C/10P/70F	🟫	🟫			🟩
20C/80F	🟫	🟫	20P/80F	🟩	🟩
30C/70P	80C/20F		80C/10P/10F		🟩

30C/60P/10F	70C/30F		70C/10P/20F	20C/80P	🟩
30C/50P/20F	60C/40F		60C/10P/30F		🟩
30C/40P/30F	50C/50F		50C/10P/40F		🟩
30C/30P/40F	40C/60F		40C/10P/50F		🟩
30C/20P/50F	🟫	30C/70F	20C/80P		🟩
30C/10P/60F	🟫	🟫			🟩
30C/70F	🟫	🟫	30P/70F	🟩	🟩
40C/60P	70C/30F		70C/20P/10F		🟩
40C/50P/10F	60C/40F		60C/20P/20F	20C/80P	🟩
40C/40P/20F	50C/50F		50C/20P/30F		🟩
40C/30P/30F	40C/60F		40C/20P/40F		🟩
40C/20P/40F	🟫	30C/70F	20C/80P		🟩
40C/10P/50F	🟫	🟫			🟩
40C/60F	🟫	🟫	40P/60F	🟩	🟩
50C/50P	60C/40F		60C/30P/10F	20C/80P	🟩
50C/40P/10F	50C/50F		50C/30P/20F		🟩
50C/30P/20F	40C/60F		40C/30P/30F		🟩
50C/20P/30F	🟫	30C/70F	20C/80P		🟩
50C/10P/40F	🟫	🟫			🟩
50C/50F	🟫	🟫		🟩	🟩
60C/40P	50C/50F		50C/40P/10F	20C/80P	🟩
60C/30P/10F	40C/60F		40C/40P/20F		🟩
60C/20P/20F	🟫	30C/70F	20C/80P		🟩
60C/10P/30F	🟫	🟫			🟩
60C/40F	🟫	🟫		🟩	🟩
70C/30P	40C/60F		40C/50P/10F	20C/80P	🟩
70C/20P/10F	🟫	30C/70F	20C/80P		🟩
70C/10P/20F	🟫	🟫			🟩
70C/30F	🟫	🟫		🟩	🟩
80C/20P	🟫	30C/70F		20C/80P	🟩
80C/10P/10F	🟫	🟫			🟩
80C/20F	🟫	🟫		🟩	🟩
90C/10P	🟫	🟫		🟩	🟩
90C/10F	🟫	🟫		🟩	🟩
100C	🟫	🟫	🟩	🟩	🟩

Table C.3. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.63 US$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb^{-1})				
	0.16	0.19	0.22	0.25	0.28 to 0.42
100P	🟫	🟦	🟦	80C/20P	🟩
90P/10F	🟫	90C/10F	90C/10P		🟩
80P/20F	🟫	80C/20F	80C/20P		🟩
70P/30F	🟫	70C/30F	70C/30P	20C/80P	🟩
60P/40F	🟫	60C/40F	60C/40P		🟩
50P/50F	🟫	50C/50F	50C/50P		🟩
40P/60F	🟫	40C/60F	40C/60P		🟩
30P/70F	🟫	30C/70F	30C/70P		🟩
20P/80F	🟫	20C/80F	20C/80P		🟩
10P/90F	🟫	10C/90F			🟩
100F	🟫	🟫		🟩	🟩
10C/90P	🟫	90C/10F	90C/10P	80C/20P	🟩
10C/80P/10F	🟫	80C/20F	80C/20P		🟩
10C/70P/20F	🟫	70C/30F	70C/30P	20C/80P	🟩
10C/60P/30F	🟫	60C/40F	60C/40P		🟩
10C/50P/40F	🟫	50C/50F	50C/50P		🟩
10C/40P/50F	🟫	40C/60F	40C/60P		🟩
10C/30P/60F	🟫	30C/70F	30C/70P		🟩
10C/20P/70F	🟫	20C/80F	20C/80P		🟩
10C/10P/80F	🟫	10C/90F			🟩
10C/90F	🟫	🟫		🟩	🟩
20C/80P	90C/10F				🟩
20C/70P/10F	80C/20F			20C/80P	🟩
20C/60P/20F	70C/30F				🟩
20C/50P/30F	60C/40F				🟩
20C/40P/40F	50C/50F		40C/60P		🟩
20C/30P/50F	40C/60F		30C/70P		🟩
20C/20P/60F	30C/70F		20C/80P		🟩
20C/10P/70F	🟫	10C/90F			🟩
20C/80F	🟫	🟫		🟩	🟩
30C/70P	80C/20F		80C/10P/10F		🟩

30C/60P/10F	70C/30F		70C/10P/20F	20C/80P	🟩
30C/50P/20F	60C/40F		60C/10P/30F		🟩
30C/40P/30F	50C/50F		40C/60P		🟩
30C/30P/40F	40C/60F		30C/70P		🟩
30C/20P/50F	30C/70F		20C/80P		🟩
30C/10P/60F	🟫	10C/90F			🟩
30C/70F	🟫	🟫		🟩	🟩
40C/60P	70C/30F		70C/20P/10F	20C/80P	🟩
40C/50P/10F	60C/40F		60C/20P/20F		🟩
40C/40P/20F	50C/50F		40C/60P		🟩
40C/30P/30F	40C/60F		30C/70P		🟩
40C/20P/40F	30C/70F		20C/80P		🟩
40C/10P/50F	🟫	10C/90F			🟩
40C/60F	🟫	🟫		🟩	🟩
50C/50P	60C/40F		60C/30P/10F	20C/80P	🟩
50C/40P/10F	50C/50F		40C/60P		🟩
50C/30P/20F	40C/60F		30C/70P		🟩
50C/20P/30F	30C/70F		20C/80P		🟩
50C/10P/40F	🟫	10C/90F			🟩
50C/50F	🟫	🟫		🟩	🟩
60C/40P	50C/50F		40C/60P	20C/80P	🟩
60C/30P/10F	40C/60F		30C/70P		🟩
60C/20P/20F	30C/70F		20C/80P		🟩
60C/10P/30F	🟫	10C/90F			🟩
60C/40F	🟫	🟫		🟩	🟩
70C/30P	40C/60F		30C/70P	20C/80P	🟩
70C/20P/10F	30C/70F		20C/80P		🟩
70C/10P/20F	🟫	10C/90F			🟩
70C/30F	🟫	🟫		🟩	🟩
80C/20P	30C/70F	30C/70F		20C/80P	🟩
80C/10P/10F	🟫	10C/90F			🟩
80C/20F	🟫	🟫		🟩	🟩
90C/10P	🟫	20C/70P/10F		10C/90P	🟩
90C/10F	🟫	🟫		🟩	🟩
100C	🟫	🟫	🟩	🟩	🟩

Table C.4. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.69 US\$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb-1)					
	0.16	0.19	0.22	0.25	0.28	0.30 to 0.42
100P	🟦	🟦	🟦	🟦	20C/80P	🟩
90P/10F	90C/10F		90C/10P			🟩
80P/20F	80C/20F		80C/20P	80C/20P		🟩
70P/30F	70C/30F			70C/30P		🟩
60P/40F	60C/40F			60C/40P		🟩
50P/50F	50C/50F			50C/50P		🟩
40P/60F	40C/60F			40C/60P		🟩
30P/70F	30C/70F			30C/70P		🟩
20P/80F	20C/80F			20C/80P		🟩
10P/90F	10C/90F				🟩	🟩
100F	🟫	🟫			🟩	🟩
10C/90P	90C/10F			90C/10P	20C/80P	🟩
10C/80P/10F	80C/20F			80C/20P		🟩
10C/70P/20F	70C/30F			70C/30P		🟩
10C/60P/30F	60C/40F			60C/40P		🟩
10C/50P/40F	50C/50F			50C/50P		🟩
10C/40P/50F	40C/60F			40C/60P		🟩
10C/30P/60F	30C/70F			30C/70P		🟩
10C/20P/70F	20C/80F			20C/80P		🟩
10C/10P/80F	10C/90F				🟩	🟩
10C/90F	🟫	🟫			🟩	🟩
20C/80P	80C/20F	80C/20P		80C/20P	20C/80P	🟩
20C/70P/10F	70C/30F	80C/20F		70C/30P		🟩
20C/60P/20F	60C/40F	70C/30F		60C/40P		🟩
20C/50P/30F	50C/50F			50C/50P		🟩
20C/40P/40F	40C/60F			40C/60P		🟩
20C/30P/50F	30C/70F			30C/70P		🟩
20C/20P/60F	20C/80F			20C/80P		🟩
20C/10P/70F	10C/90F				🟩	🟩
20C/80F	🟫	🟫			🟩	🟩

30C/70P	70C/30F	70C/30P			20C/80P	🟩
30C/60P/10F	60C/40F	60C/30P/10F	70C/ 30P	60C/40P		🟩
30C/50P/20F	50C/50F	50C/30P/20F		50C/50P		🟩
30C/40P/30F	40C/60F	40C/30P/30F		40C/60P		🟩
30C/30P/40F	30C/70F		30C/70P			🟩
30C/20P/50F	20C/80F		20C/80P			🟩
30C/10P/60F	10C/90F				🟩	🟩
30C/70F	🟫	🟫			🟩	🟩
40C/60P	60C/40F	60C/40P	60C/ 40P	60C/40P	20C/80P	🟩
40C/50P/10F	50C/50F	50C/40P/10F		50C/50P		🟩
40C/40P/20F	40C/60F	40C/40P/20F	40C/60P			🟩
40C/30P/30F	30C/70F	30C/40P/30F	30C/70P			🟩
40C/20P/40F	20C/80F	20C/40P/40F	20C/80P			🟩
40C/10P/50F	10C/90F				🟩	🟩
40C/60F	🟫	🟫			🟩	🟩
50C/50P	50C/50F	50C/50P	50C/50P		20C/80P	🟩
50C/40P/10F	40C/60F	40C/50P/10F	40C/60P			🟩
50C/30P/20F	30C/70F	30C/50P/20F	30C/70P			🟩
50C/20P/30F	20C/80F	20C/50P/30F	20C/80P			🟩
50C/10P/40F	10C/90F	20C/50P/30F			🟩	🟩
50C/50F	🟫	🟫			🟩	🟩
60C/40P	40C/60F	40C/60P			20C/80P	🟩
60C/30P/10F	30C/70F	30C/60P/10F	30C/70P			🟩
60C/20P/20F	20C/80F	20C/60P/20F	20C/80P			🟩
60C/10P/30F	10C/90F				🟩	🟩
60C/40F	🟫				🟩	🟩
70C/30P	30C/70F	30C/70P			20C/80P	🟩
70C/20P/10F	20C/80F	20C/70P/10F	20C/80P	20C/80P		🟩
70C/10P/20F	10C/90F				🟩	🟩
70C/30F	🟫				🟩	🟩
80C/20P	20C/80F	20C/80P			20C/80P	🟩
80C/10P/10F	10C/90F				🟩	🟩
80C/20F	🟫				🟩	🟩
90C/10P	10C/90F			10C/90P	🟩	🟩
90C/10F	🟫			🟩	🟩	🟩
100C	🟫		🟩	🟩	🟩	🟩

Table C.5. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.74 US\$ lb^{-1}

FROM STATE	Price of Peanut (US\$ lb-1)					
	0.16	0.19	0.22	0.25	0.28	0.30 to 0.42
100P	🟦	🟦	🟦	🟦	🟦	🟩
90P/10F	90C/10F	🟦	🟦	90C/10P		🟩
80P/20F	80C/20F	🟦	🟦	80C/20P		🟩
70P/30F		🟦	🟦	70C/30P		🟩
60P/40F		🟦	🟦	60C/40P		🟩
50P/50F		🟦	🟦	50C/50P		🟩
40P/60F		🟦	🟦	40C/60P		🟩
30P/70F		🟦	🟦	30C/70P		🟩
20P/80F		🟦	🟦	20C/80P	20C/80P	🟩
10P/90F		🟦	🟦		10C/90P	🟩
100F		🟦	🟦		🟩	🟩
10C/90P		🟦	90C/10P	90C/10P		🟩
10C/80P/10F		🟦		80C/20P		🟩
10C/70P/20F		🟦		70C/30P		🟩
10C/60P/30F		🟦		60C/40P		🟩
10C/50P/40F		🟦		50C/50P		🟩
10C/40P/50F		🟦		40C/60P		🟩
10C/30P/60F		🟦		30C/70P		🟩
10C/20P/70F		🟦		20C/80P	20C/80P	🟩
10C/10P/80F		🟦			10C/90P	🟩
10C/90F		🟦			🟩	🟩
20C/80P		🟦	80C/20P	80C/20P		🟩
20C/70P/10F	90C/10F	🟦		70C/30P		🟩
20C/60P/20F	80C/20F	🟦		60C/40P		🟩
20C/50P/30F		🟦		50C/50P		🟩
20C/40P/40F		🟦		40C/60P		🟩
20C/30P/50F		🟦		30C/70P		🟩
20C/20P/60F		🟦		20C/80P	20C/80P	🟩
20C/10P/70F		🟦			10C/90P	🟩
20C/80F		🟦			🟩	🟩

30C/70P	🟦	🟦	70C/30P	70C/30P		🟩
30C/60P/10F	90C/10F	🟦		60C/40P		🟩
30C/50P/20F	80C/20F	🟦		50C/50P		🟩
30C/40P/30F		🟦		40C/60P		🟩
30C/30P/40F		🟦		30C/70P		🟩
30C/20P/50F		🟦		20C/80P	20C/80P	🟩
30C/10P/60F		🟦			10C/90P	🟩
30C/70F		🟦			🟩	🟩
40C/60P	🟦	🟦	60C/40P	60C/40P		🟩
40C/50P/10F	90C/10F	🟦		50C/50P		🟩
40C/40P/20F	80C/20F	🟦		40C/60P		🟩
40C/30P/30F		🟦		30C/70P		🟩
40C/20P/40F		🟦		20C/80P	20C/80P	🟩
40C/10P/50F		🟦			10C/90P	🟩
40C/60F		🟦			🟩	🟩
50C/50P	🟦	🟦	50C/50P	50C/50P		🟩
50C/40P/10F	90C/10F	🟦		40C/60P		🟩
50C/30P/20F	80C/20F	🟦		30C/70P		🟩
50C/20P/30F		🟦		20C/80P	20C/80P	🟩
50C/10P/40F		🟦			10C/90P	🟩
50C/50F		🟦			🟩	🟩
60C/40P	🟦	🟦	40C/60P	40C/60P		🟩
60C/30P/10F	90C/10F	🟦		30C/70P		🟩
60C/20P/20F	80C/20F	🟦		20C/80P	20C/80P	🟩
60C/10P/30F		🟦			10C/90P	🟩
60C/40F		🟦			🟩	🟩
70C/30P	🟦	🟦	30C/70P	30C/70P	30C/70P	🟩
70C/20P/10F	90C/10F	🟦		20C/80P	20C/80P	🟩
70C/10P/20F	80C/20F	🟦			10C/90P	🟩
70C/30F		🟦			🟩	🟩
80C/20P	🟦	🟦	20C/80P		20C/80P	🟩
80C/10P/10F	90C/10F	🟦			10C/90P	🟩
80C/20F	80C/20F	🟦			🟩	🟩
80C/10P	🟦	🟦		10C/90P		🟩
80C/10F	80C/20F	🟦		🟩	🟩	🟩
100C		🟦	🟩	🟩	🟩	🟩

Table C.6. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.80 US\$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb-1)					
	0.16 to 0.19	0.22	0.25	0.28	0.3	0.33 to 0.42
100P	🟦	🟦	🟦	🟦	🟦	🟩
90P/10F	🟦	🟦	🟦	90C/10P		🟩
80P/20F	🟦	🟦	80C/20P	80C/20P		🟩
70P/30F	🟦	🟦		70C/30P		🟩
60P/40F	🟦	🟦		60C/40P		🟩
50P/50F	🟦	🟦		50C/50P		🟩
40P/60F	🟦	🟦		40C/60P		🟩
30P/70F	🟦	🟦		30C/70P		🟩
20P/80F	🟦	🟦		20C/80P		🟩
10P/90F	🟦	🟦		10C/90P		🟩
100F	🟦	🟦		🟩	🟩	🟩
10C/90P	🟦	90C/10P	90C/10P	90C/10P		🟩
10C/80P/10F	🟦		80C/20P	80C/20P		🟩
10C/70P/20F	🟦			70C/30P		🟩
10C/60P/30F	🟦			60C/40P		🟩
10C/50P/40F	🟦			50C/50P		🟩
10C/40P/50F	🟦			40C/60P		🟩
10C/30P/60F	🟦			30C/70P		🟩
10C/20P/70F	🟦			20C/80P		🟩
10C/10P/80F	🟦			10C/90P		🟩
10C/90F	🟦			🟩	🟩	🟩
20C/80P	🟦	80C/20P		80C/20P		🟩
20C/70P/10F	🟦			70C/30P		🟩
20C/60P/20F	🟦			60C/40P		🟩
20C/50P/30F	🟦			50C/50P		🟩
20C/40P/40F	🟦			40C/60P		🟩
20C/30P/50F	🟦			30C/70P		🟩
20C/20P/60F	🟦			20C/80P		🟩
20C/10P/70F	🟦			10C/90P		🟩
20C/80F	🟦			🟩	🟩	🟩

30C/70P	🟦	70C/30P		70C/30P		🟩
30C/60P/10F	🟦			60C/40P		🟩
30C/50P/20F	🟦			50C/50P		🟩
30C/40P/30F	🟦			40C/60P		🟩
30C/30P/40F	🟦			30C/70P		🟩
30C/20P/50F	🟦			20C/80P		🟩
30C/10P/60F	🟦			10C/90P		🟩
30C/70F	🟦			🟩	🟩	🟩
40C/60P	🟦	60C/40P		60C/40P		🟩
40C/50P/10F	🟦			50C/50P		🟩
40C/40P/20F	🟦			40C/60P		🟩
40C/30P/30F	🟦			30C/70P		🟩
40C/20P/40F	🟦			20C/80P		🟩
40C/10P/50F	🟦			10C/90P		🟩
40C/60F	🟦			🟩	🟩	🟩
50C/50P	🟦	50C/50P		50C/50P		🟩
50C/40P/10F	🟦			40C/60P		🟩
50C/30P/20F	🟦			30C/70P		🟩
50C/20P/30F	🟦			20C/80P		🟩
50C/10P/40F	🟦			10C/90P		🟩
50C/50F	🟦			🟩	🟩	🟩
60C/40P	🟦	40C/60P		40C/60P		🟩
60C/30P/10F	🟦			30C/70P		🟩
60C/20P/20F	🟦			20C/80P		🟩
60C/10P/30F	🟦			10C/90P		🟩
60C/40F	🟦			🟩	🟩	🟩
70C/30P	🟦	30C/70P		30C/70P		🟩
70C/20P/10F	🟦			20C/80P		🟩
70C/10P/20F	🟦			10C/90P		🟩
70C/30F	🟦			🟩	🟩	🟩
80C/20P	🟦	20C/80P	20C/80P	20C/80P		🟩
80C/10P/10F	🟦			10C/90P		🟩
80C/20F	🟦			🟩	🟩	🟩
90C/10P	🟦		10C/90P	10C/90P		🟩
90C/10F	🟦			🟩	🟩	🟩
100C	🟦		🟩	🟩	🟩	🟩

Table C.7. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.85 US\$ lb^{-1}

FROM STATE	Price of Peanut (US\$ lb-1)						
	0.16 to 0.19	0.22	0.25	0.28	0.3	0.33	0.36 to 0.42
100P	🟦	🟦	🟦	🟦	🟦	80C/20P	🟩
90P/10F	🟦	🟦	🟦	90C/10P			🟩
80P/20F	🟦	🟦	🟦	80C/20P			🟩
70P/30F	🟦	🟦	🟦	70C/30P			🟩
60P/40F	🟦	🟦	🟦	60C/40P			🟩
50P/50F	🟦	🟦	🟦	50C/50P			🟩
40P/60F	🟦	🟦	🟦	40C/60P			🟩
30P/70F	🟦	🟦	🟦	30C/70P			🟩
20P/80F	🟦	🟦	🟦	20C/80P	20C/80P		🟩
10P/90F	🟦	🟦	🟦		10C/90P		🟩
100F	🟦	🟦	🟦		🟩	🟩	🟩
10C/90P	🟦	90C/10P		90C/10P		80C/20P	🟩
10C/80P/10F	🟦			80C/20P			🟩
10C/70P/20F	🟦			70C/30P			🟩
10C/60P/30F	🟦			60C/40P			🟩
10C/50P/40F	🟦			50C/50P			🟩
10C/40P/50F	🟦			40C/60P			🟩
10C/30P/60F	🟦			30C/70P			🟩
10C/20P/70F	🟦			20C/80P	20C/80P		🟩
10C/10P/80F	🟦				10C/90P		🟩
10C/90F	🟦				🟩	🟩	🟩
20C/80P	🟦	80C/20P	80C/20P	80C/20P			🟩
20C/70P/10F	🟦			70C/30P			🟩
20C/60P/20F	🟦			60C/40P			🟩
20C/50P/30F	🟦			50C/50P			🟩
20C/40P/40F	🟦			40C/60P			🟩
20C/30P/50F	🟦			30C/70P			🟩
20C/20P/60F	🟦			20C/80P	20C/80P		🟩
20C/10P/70F	🟦				10C/90P		🟩
20C/80F	🟦				🟩	🟩	🟩

30C/70P	🟦		70C/30P	70C/30P			🟩
30C/60P/10F	🟦			60C/40P			🟩
30C/50P/20F	🟦			50C/50P			🟩
30C/40P/30F	🟦			40C/60P			🟩
30C/30P/40F	🟦			30C/70P			🟩
30C/20P/50F	🟦			20C/80P	20C/80P		🟩
30C/10P/60F	🟦				10C/90P		🟩
30C/70F	🟦				🟩	🟩	🟩
40C/60P	🟦		60C/40P	60C/40P			🟩
40C/50P/10F	🟦			50C/50P			🟩
40C/40P/20F	🟦			40C/60P			🟩
40C/30P/30F	🟦			30C/70P			🟩
40C/20P/40F	🟦			20C/80P	20C/80P		🟩
40C/10P/50F	🟦				10C/90P		🟩
40C/60F	🟦				🟩	🟩	🟩
50C/50P	🟦		50C/50P	50C/50P			🟩
50C/40P/10F	🟦			40C/60P			🟩
50C/30P/20F	🟦			30C/70P			🟩
50C/20P/30F	🟦			20C/80P	20C/80P		🟩
50C/10P/40F	🟦				10C/90P		🟩
50C/50F	🟦				🟩	🟩	🟩
60C/40P	🟦		40C/60P	40C/60P			🟩
60C/30P/10F	🟦			30C/70P			🟩
60C/20P/20F	🟦			20C/80P	20C/80P		🟩
60C/10P/30F	🟦				10C/90P		🟩
60C/40F	🟦				🟩	🟩	🟩
70C/30P	🟦		30C/70P	30C/70P			🟩
70C/20P/10F	🟦			20C/80P	20C/80P		🟩
70C/10P/20F	🟦				10C/90P		🟩
70C/30F	🟦				🟩	🟩	🟩
80C/20P	🟦		20C/80P		20C/80P		🟩
80C/10P/10F	🟦				10C/90P		🟩
80C/20F	🟦	20C/80P			🟩	🟩	🟩
90C/10P	🟦	80C/20P	10C/90P	10C/90P			🟩
90C/10F	🟦	20C/80P		🟩	🟩	🟩	🟩
100C	🟦		🟩	🟩	🟩	🟩	🟩

Table C.8. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.91 US$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb-1)					
	0.16 to 0.22	0.25	0.28	0.30	0.33	0.36 to 0.42
100P	🟦	🟦	🟦	🟦	🟦	🟩
90P/10F	🟦	🟦	🟦	90C/10P		🟩
80P/20F	🟦	🟦	🟦	80C/20P		🟩
70P/30F	🟦	🟦	🟦	70C/30P		🟩
60P/40F	🟦	🟦	🟦	60C/40P		🟩
50P/50F	🟦	🟦	🟦	50C/50P		🟩
40P/60F	🟦	🟦	🟦	40C/60P		🟩
30P/70F	🟦	🟦	🟦	30C/70P		🟩
20P/80F	🟦	🟦	🟦	20C/80P	20C/80P	🟩
10P/90F	🟦	🟦	🟦		10C/90P	🟩
100F	🟦	🟦	🟦	🟩	🟩	🟩
10C/90P	🟦	90C/10P		90C/10P		🟩
10C/80P/10F	🟦			80C/20P		🟩
10C/70P/20F	🟦			70C/30P		🟩
10C/60P/30F	🟦			60C/40P		🟩
10C/50P/40F	🟦			50C/50P		🟩
10C/40P/50F	🟦			40C/60P		🟩
10C/30P/60F	🟦			30C/70P		🟩
10C/20P/70F	🟦			20C/80P	20C/80P	🟩
10C/10P/80F	🟦				10C/90P	🟩
10C/90F	🟦			🟩	🟩	🟩
20C/80P	🟦	80C/20P		80C/20P		🟩
20C/70P/10F	🟦			70C/30P		🟩
20C/60P/20F	🟦			60C/40P		🟩
20C/50P/30F	🟦			50C/50P		🟩
20C/40P/40F	🟦			40C/60P		🟩
20C/30P/50F	🟦			30C/70P		🟩
20C/20P/60F	🟦			20C/80P	20C/80P	🟩
20C/10P/70F	🟦				10C/90P	🟩
20C/80F	🟦			🟩	🟩	🟩

30C/70P	🟦	70C/30P	70C/30P		🟩
30C/60P/10F	🟦		60C/40P		🟩
30C/50P/20F	🟦		50C/50P		🟩
30C/40P/30F	🟦		40C/60P		🟩
30C/30P/40F	🟦		30C/70P		🟩
30C/20P/50F	🟦		20C/80P	20C/80P	🟩
30C/10P/60F	🟦			10C/90P	🟩
30C/70F	🟦		🟩	🟩	🟩
40C/60P	🟦	60C/40P	60C/40P		🟩
40C/50P/10F	🟦		50C/50P		🟩
40C/40P/20F	🟦		40C/60P		🟩
40C/30P/30F	🟦		30C/70P		🟩
40C/20P/40F	🟦		20C/80P	20C/80P	🟩
40C/10P/50F	🟦			10C/90P	🟩
40C/60F	🟦		🟩	🟩	🟩
50C/50P	🟦	50C/50P	50C/50P		🟩
50C/40P/10F	🟦		40C/60P		🟩
50C/30P/20F	🟦		30C/70P		🟩
50C/20P/30F	🟦		20C/80P	20C/80P	🟩
50C/10P/40F	🟦			10C/90P	🟩
50C/50F	🟦		🟩	🟩	🟩
60C/40P	🟦	40C/60P	40C/60P		🟩
60C/30P/10F	🟦		30C/70P		🟩
60C/20P/20F	🟦		20C/80P	20C/80P	🟩
60C/10P/30F	🟦			10C/90P	🟩
60C/40F	🟦		🟩	🟩	🟩
70C/30P	🟦	30C/70P	30C/70P		🟩
70C/20P/10F	🟦		20C/80P	20C/80P	🟩
70C/10P/20F	🟦			10C/90P	🟩
70C/30F	🟦		🟩	🟩	🟩
80C/20P	🟦	20C/80P	20C/80P	20C/80P	🟩
80C/10P/10F	🟦			10C/90P	🟩
80C/20F	🟦		🟩	🟩	🟩
90C/10P	🟦	10C/90P	10C/90P		🟩
90C/10F	🟦		🟩	🟩	🟩
100C	🟦	🟩 🟩	🟩	🟩	🟩

Table C.9. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 0.96 US$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb-1)						
	0.16 to 0.22	0.25	0.28	0.3	0.33	0.36	0.39 to 0.42
100P	🟦	🟦	🟦	🟦	🟦	🟦	🟩
90P/10F	🟦	🟦	🟦	🟦	90C/10P		🟩
80P/20F	🟦	🟦	🟦	🟦	80C/20P		🟩
70P/30F	🟦	🟦	🟦	🟦	70C/30P		🟩
60P/40F	🟦	🟦	🟦	🟦	60C/40P		🟩
50P/50F	🟦	🟦	🟦	🟦	50C/50P		🟩
40P/60F	🟦	🟦	🟦	🟦	40C/60P		🟩
30P/70F	🟦	🟦	🟦	🟦	30C/70P		🟩
20P/80F	🟦	🟦	🟦	🟦	20C/80P		🟩
10P/90F	🟦	🟦	🟦	🟦	10C/90P		🟩
100F	🟦	🟦	🟦	🟦	🟩	🟩	🟩
10C/90P	🟦	90C/10P			90C/10P		🟩
10C/80P/10F	🟦				80C/20P		🟩
10C/70P/20F	🟦				70C/30P		🟩
10C/60P/30F	🟦				60C/40P		🟩
10C/50P/40F	🟦				50C/50P		🟩
10C/40P/50F	🟦				40C/60P		🟩
10C/30P/60F	🟦				30C/70P		🟩
10C/20P/70F	🟦				20C/80P		🟩
10C/10P/80F	🟦				10C/90P		🟩
10C/90F	🟦				🟩	🟩	🟩
20C/80P	🟦	80C/20P			80C/20P		🟩
20C/70P/10F	🟦				70C/30P		🟩
20C/60P/20F	🟦				60C/40P		🟩
20C/50P/30F	🟦				50C/50P		🟩
20C/40P/40F	🟦				40C/60P		🟩
20C/30P/50F	🟦				30C/70P		🟩
20C/20P/60F	🟦				20C/80P		🟩
20C/10P/70F	🟦				10C/90P		🟩
20C/80F	🟦				🟩	🟩	🟩

<table>
<tr><td>30C/70P</td><td>🟦</td><td colspan="3" rowspan="8">70C/30P</td><td colspan="2">70C/30P</td><td>🟩</td></tr>
<tr><td>30C/60P/10F</td><td>🟦</td><td colspan="2">60C/40P</td><td>🟩</td></tr>
<tr><td>30C/50P/20F</td><td>🟦</td><td colspan="2">50C/50P</td><td>🟩</td></tr>
<tr><td>30C/40P/30F</td><td>🟦</td><td colspan="2">40C/60P</td><td>🟩</td></tr>
<tr><td>30C/30P/40F</td><td>🟦</td><td colspan="2">30C/70P</td><td>🟩</td></tr>
<tr><td>30C/20P/50F</td><td>🟦</td><td colspan="2">20C/80P</td><td>🟩</td></tr>
<tr><td>30C/10P/60F</td><td>🟦</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>30C/70F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>40C/60P</td><td>🟦</td><td colspan="3" rowspan="7">60C/40P</td><td colspan="2">60C/40P</td><td>🟩</td></tr>
<tr><td>40C/50P/10F</td><td>🟦</td><td colspan="2">50C/50P</td><td>🟩</td></tr>
<tr><td>40C/40P/20F</td><td>🟦</td><td colspan="2">40C/60P</td><td>🟩</td></tr>
<tr><td>40C/30P/30F</td><td>🟦</td><td colspan="2">30C/70P</td><td>🟩</td></tr>
<tr><td>40C/20P/40F</td><td>🟦</td><td colspan="2">20C/80P</td><td>🟩</td></tr>
<tr><td>40C/10P/50F</td><td>🟦</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>40C/60F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>50C/50P</td><td>🟦</td><td colspan="3" rowspan="6">50C/50P</td><td colspan="2">50C/50P</td><td>🟩</td></tr>
<tr><td>50C/40P/10F</td><td>🟦</td><td colspan="2">40C/60P</td><td>🟩</td></tr>
<tr><td>50C/30P/20F</td><td>🟦</td><td colspan="2">30C/70P</td><td>🟩</td></tr>
<tr><td>50C/20P/30F</td><td>🟦</td><td colspan="2">20C/80P</td><td>🟩</td></tr>
<tr><td>50C/10P/40F</td><td>🟦</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>50C/50F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>60C/40P</td><td>🟦</td><td colspan="3" rowspan="5">40C/60P</td><td colspan="2">40C/60P</td><td>🟩</td></tr>
<tr><td>60C/30P/10F</td><td>🟦</td><td colspan="2">30C/70P</td><td>🟩</td></tr>
<tr><td>60C/20P/20F</td><td>🟦</td><td colspan="2">20C/80P</td><td>🟩</td></tr>
<tr><td>60C/10P/30F</td><td>🟦</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>60C/40F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>70C/30P</td><td>🟦</td><td colspan="3" rowspan="4">30C/70P</td><td colspan="2">30C/70P</td><td>🟩</td></tr>
<tr><td>70C/20P/10F</td><td>🟦</td><td colspan="2">20C/80P</td><td>🟩</td></tr>
<tr><td>70C/10P/20F</td><td>🟦</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>70C/30F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>80C/20P</td><td>🟦</td><td rowspan="6">20C/80P</td><td colspan="2" rowspan="3">20C/80P</td><td colspan="2">20C/80P</td><td>🟩</td></tr>
<tr><td>80C/10P/10F</td><td>🟦</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>80C/20F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>90C/10P</td><td>🟦</td><td colspan="2" rowspan="2">10C/90P</td><td colspan="2">10C/90P</td><td>🟩</td></tr>
<tr><td>90C/10F</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
<tr><td>100C</td><td>🟦</td><td>🟩</td><td>🟩</td><td>🟩</td><td>🟩</td><td>🟩</td></tr>
</table>

Table C.10. Optimal decision rule in (t-1) for the cash rent (CR) scenario assuming price of cotton at 1.02 US$ lb^{-1}

FROM STATE	Price of Peanut (US$ lb-1)						
	0.16 to 0.25	0.28	0.3	0.33	0.36	0.39	0.42
100P	🟦	🟦	🟦	🟦	🟦	🟦	🟩
90P/10F	🟦	🟦	🟦	90C/10P			🟩
80P/20F	🟦	🟦	🟦	80C/20P			🟩
70P/30F	🟦	🟦	🟦	70C/30P			🟩
60P/40F	🟦	🟦	🟦	60C/40P			🟩
50P/50F	🟦	🟦	🟦	50C/50P			🟩
40P/60F	🟦	🟦	🟦	40C/60P			🟩
30P/70F	🟦	🟦	🟦	30C/70P			🟩
20P/80F	🟦	🟦	🟦	20C/80P	20C/80P		🟩
10P/90F	🟦	🟦	🟦		10C/90P		🟩
100F	🟦	🟦	🟦		🟩	🟩	🟩
10C/90P	🟦	90C/10P		90C/10P			🟩
10C/80P/10F	🟦			80C/20P			🟩
10C/70P/20F	🟦			70C/30P			🟩
10C/60P/30F	🟦			60C/40P			🟩
10C/50P/40F	🟦			50C/50P			🟩
10C/40P/50F	🟦			40C/60P			🟩
10C/30P/60F	🟦			30C/70P			🟩
10C/20P/70F	🟦			20C/80P	20C/80P		🟩
10C/10P/80F	🟦				10C/90P		🟩
10C/90F	🟦				🟩	🟩	🟩
20C/80P	🟦	80C/20P		80C/20P			🟩
20C/70P/10F	🟦			70C/30P			🟩
20C/60P/20F	🟦			60C/40P			🟩
20C/50P/30F	🟦			50C/50P			🟩
20C/40P/40F	🟦			40C/60P			🟩
20C/30P/50F	🟦			30C/70P			🟩
20C/20P/60F	🟦			20C/80P	20C/80P		🟩
20C/10P/70F	🟦				10C/90P		🟩
20C/80F	🟦				🟩	🟩	🟩

30C/70P	🟦	70C/30P	70C/30P			🟩
30C/60P/10F	🟦		60C/40P			🟩
30C/50P/20F	🟦		50C/50P			🟩
30C/40P/30F	🟦		40C/60P			🟩
30C/30P/40F	🟦		30C/70P			🟩
30C/20P/50F	🟦		20C/80P	20C/80P		🟩
30C/10P/60F	🟦			10C/90P		🟩
30C/70F	🟦			🟩	🟩	🟩
40C/60P	🟦	60C/40P	60C/40P			🟩
40C/50P/10F	🟦		50C/50P			🟩
40C/40P/20F	🟦		40C/60P			🟩
40C/30P/30F	🟦		30C/70P			🟩
40C/20P/40F	🟦		20C/80P	20C/80P		🟩
40C/10P/50F	🟦			10C/90P		🟩
40C/60F	🟦			🟩	🟩	🟩
50C/50P	🟦	50C/50P	50C/50P			🟩
50C/40P/10F	🟦		40C/60P			🟩
50C/30P/20F	🟦		30C/70P			🟩
50C/20P/30F	🟦		20C/80P	20C/80P		🟩
50C/10P/40F	🟦			10C/90P		🟩
50C/50F	🟦			🟩	🟩	🟩
60C/40P	🟦	40C/60P	40C/60P			🟩
60C/30P/10F	🟦		30C/70P			🟩
60C/20P/20F	🟦		20C/80P	20C/80P		🟩
60C/10P/30F	🟦			10C/90P		🟩
60C/40F	🟦			🟩	🟩	🟩
70C/30P	🟦	30C/70P	30C/70P			🟩
70C/20P/10F	🟦		20C/80P	20C/80P		🟩
70C/10P/20F	🟦			10C/90P		🟩
70C/30F	🟦			🟩	🟩	🟩
80C/20P	🟦	20C/80P	20C/80P	20C/80P		🟩
80C/10P/10F	🟦			10C/90P		🟩
80C/20F	🟦			🟩	🟩	🟩
90C/10P	🟦	10C/90P	10C/90P			🟩
90C/10F	🟦		🟩	🟩	🟩	🟩
100C	🟦	🟩 🟩	🟩	🟩	🟩	🟩