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Evaluating the Economic Effects of Using Broiler Litter as an Alternative Fertilizer for a Corn-Wheat-Soybean Cropping Sequence in South Carolina

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EVALUATING THE ECONOMIC EFFECTS OF USING BROILER LITTER AS AN ALTERNATIVE FERTILIZER FOR A CORN-WHEAT-SOYBEAN CROPPING SEQUENCE IN SOUTH CAROLINA

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ABSTRACT

This thesis evaluates the profitability of a standard commercial inorganic fertilization practice vis-à-vis the following three alternative fertilization options: i) a broiler litter only fertilization scenario ii) a 2-tons per acre broiler litter annually plus supplementary commercial inorganic fertilization scenario, and iii) a 2-tons per acre broiler litter applied every other year plus supplementary commercial inorganic fertilizer. Furthermore, the likely environmental impact of each practice was evaluated. The representative farm is a 1,000-acre row crop farm in the Upper Coastal region of South Carolina, with a corn-wheat-soybean cropping sequence. Each cropping sequence required two years for completion, and a total of 5 sequences were evaluated for all four fertilization practices.

The most profitable option evaluated was the broiler litter only fertilization practice. This option however, resulted in excess nutrients carry over especially for phosphorus over the 10-year study period. Moreover, findings are consistent with previous literature that a more profitable and environmentally efficient crop production level can be achieved by using a combination of broiler litter and commercial inorganic fertilizer. Mean NPV estimates for the four practices were compared, by evaluating their respective 95% confidence intervals and no statistically significant difference between the 2-tons per acre broiler litter annually plus supplementary commercial inorganic fertilization practice, and the 2-tons per acre broiler litter applied every other year plus supplementary commercial inorganic fertilizer was observed. The 2-ton broiler litter/acre on corn only and supplementary inorganic commercial fertilizer had the least nutrient carry-over over the 10-year study. All three proposed alternatives had better on-farm input cost efficiency compared to the standard commercial inorganic fertilizer only practice.

TABLE OF CONTENTS

Page

TITLE PAGE i

ABSTRACT ii

LIST OF TABLES vi

LIST OF FIGURES ix

CHAPTER

I. INTRODUCTION 1

Objectives of Study 6

II. LITERATURE REVIEW 8

Poultry Litter as an Alternate/Compliment Nutrient Source for Crop

Production 8

III. METHODS AND DATA 12

Representative Farm 12

Nutrient Movement Through the Simulation Cycle 14

Yield Multiplier 22

Enterprise Budget 23

Table of Contents (Continued)

Page

Net Present Value 25

IV. RESULTS AND DISCUSSIONS 27

Fertilizer Savings Analysis 27

Net Present Value Analysis 29

Nutrient Analysis 30

V. CONCLUSION 32

REFERENCES……………………………………………………………..…………36

APPENDICES

Table A1: Clemson Extension Services Sample Enterprise Budget 44

Table A2: Corn Enterprise Budget for 2-ton Broiler Litter per acre plus Supplementary

Commercial Inorganic Fertilizer 45

Table A3: Wheat Enterprise Budget for 2-ton Broiler Litter per acre plus Supplementary

Commercial Inorganic Fertilizer 46

Table A4: Soybean Enterprise Budget for 2-ton Broiler Litter per acre plus Supplementary

Commercial Inorganic Fertilizer 46

Table of Contents (Continued)

Page

Table A5: Average Revenue and Variable Cost of each Crop Under the Four Fertilization Practices 48

Table A6: Crop and Broiler Production in South Carolina at the County Level 49

LIST OF TABLES

Table Page

1 Agriculture Commodity Cash Receipts for South Carolina, 2010-2018 1

2 Average Nutrient Content of Various Types of Broiler Litter 4

3 10-year Distribution of Broiler production in Heads and Dollars, with Estimated Broiler Litter Production in South Carolina 4

4 Production Estimates of Broiler, Corn, Wheat, and Soybean in South Carolina by Agricultural District, 2017 6

5 Cropping Sequence Schedule Utilized in the Study 13

6 Nutrient Removal by Crops Commonly Grown in South Carolina 15

7 Yield Averages for Selected Crops in the Upper Coastal Region of South Carolina 15

8 Whole Crop Nutrient Requirements for Selected Crops Based on Yield Averages in Table 7 16

9 Nutrient Distribution for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using Only Commercial Inorganic Fertilizer 18

10 Nutrient Distribution for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using Broiler Litter Only 19

List of Tables (Continued)

Table Page

11 Nutrient Distribution for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using 2-ton/acre Broiler Litter on Corn and Wheat plus Supplementary Commercial Inorganic Fertilizer 20

12 Nutrient Distribution for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using 2-ton/acre Broiler Litter on Corn Only plus Supplementary Commercial Inorganic Fertilizer 21

13 Average Yearly Dryland Yield Estimates for Selected Crops, 2002-2012 23

14 Average Yearly Agricultural Commodity Prices, 2002-2012 25

15 Historical Prices of Selected Plant Nutrient 2002-2012 25

16 Economics of Using Broiler Litter as a Substitute for Commercial Inorganic Fertilizer for a Corn-Wheat-Soybean Cropping Sequence Production in South Carolina (Per Acre Farm Basis)... 28

17 Summary Statistics of NPV of Net Income using the Monte-Carlo Simulation for all Four Scenarios. 30

List of Tables (Continued)

Table Page

18 Summary Statistics of NPV of Income Above Variable Cost using the Monte-Carlo Simulation for all Four Scenarios. 30

19 Likely Excess Nutrients Applied over the 10-year study Period under each Fertilization Scenario. 31

LIST OF FIGURES

Figure Page

1 Percentage Change in Commercial Inorganic Fertilizer Prices,

2002-2007-2012. 2

CHAPTER ONE

INTRODUCTION

Agriculture in South Carolina (SC) generated $3.00 billion in crop and livestock revenue in 2017, with an average farm sale value of $2.78 billion between 2010 and 2018 (Table 1). In 2017, farming accounted for approximately 25% of total land usage in South Carolina with 24,791 farms (4.74million acres) (United States Department of Agriculture (USDA)-Census of Agriculture, 2017). Grain crops have played a significant role in the agriculture sector of South Carolina, with corn, wheat and soybean being amongst the top 5 grain crop collectively accounting for 31.33% of the total average crop output for the state over the last decade (Table 1).

Table 1: Agricultural Commodity Cash Receipts for South Carolina, 2010-2018.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Value	*Value of Receipts ($1,000)*								
Animals and products	1,609,995	1,697,380	1,756,240	1,865,055	1,713,520	1,565,300	1,335,977	1,413,881	1,415,072
Broilers	877,640	810,601	863,972	1,063,845	1,140,385	1,008,960	919,832	1,020,419	1,028,768
All Other Animals and Products[1]	732,355	886,779	892,268	801,210	573,135	556,340	416,145	393,462	386,304
Crops	1,212,227	1,220,198	1,460,784	1,369,981	1,191,471	1,062,407	949,127	1,047,348	1,143,658
Corn	184,583	163,919	238,804	255,273	186,153	119,544	135,814	175,863	192,864
Soybeans	154,779	117,055	172,225	170,746	151,341	118,445	122,117	131,199	109,474
Wheat	29,436	65,413	92,027	85,742	72,156	38,041	17,527	14,323	17,395
All Other Crops[1]	843,429	873,811	957,728	858,220	781,821	786,377	673,669	725,963	823,925
All commodities	2,822,222	2,917,577	3,217,024	3,235,036	2,904,991	2,627,706	2,285,104	2,461,229	2,558,730

Source: ERS-USDA (2019)

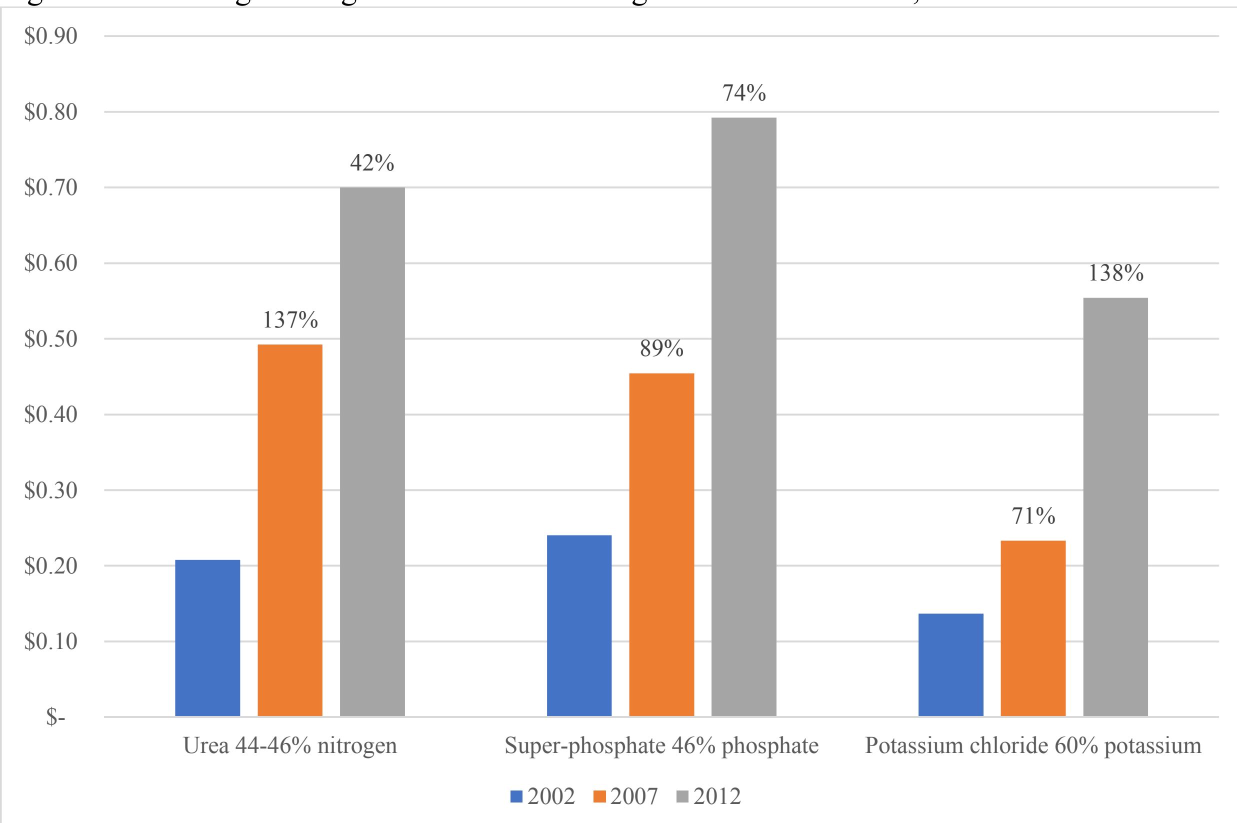
[1] All other animals and products include cattle and calves, hogs, dairy products, chicken eggs, farm chickens, turkey, sheep and lambs, honey, mohair, wool and other animals and products not classified.

[2] All other crops include rye, hay, oats, cotton, tobacco, peanuts, vegetables and melons, fruits and nuts, floriculture, mushrooms and miscellaneous crops.

Note: all dollar values are real.

For a period of five years (between 2002 to 2007), inorganic fertilizer cost increased by 137%, 89% and 71% for nitrogen, phosphorus, and potassium respectively. A further increase of 42%, 74% and 138% was observed between 2007 and 2012 (Figure 1). With this level of variability in the price of commercial inorganic fertilizer, SC grain producers will need to examine alternative fertilization practices to maintain their profitability.

Figure 1: Percentage Change in Commercial Inorganic Fertilizer Prices, 2002-2007-2012.



Source: USDA-Economic Research Service (ERS) (2014)

Broiler litter contains 13 of the essential nutrients used by crops: nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chlorine (Cl), boron (B), iron (Fe), and molybdenum (Mo) (Chastain, Camberato, and Skewes, 2019) (Table 2). Poultry is produced in relatively large quantities across the United States of America and also the largest producer in the world (19% of global poultry meat output) (USDA-Foreign Agricultural Service, 2019). It could therefore, potentially supply most of the nutrient required for crop production due to its abundance and high nutrient content.

The nutrient composition of broiler litter, however, depends on various factors such as: i) type of bird, ii) bird feed, iii) the number of grow-outs before the house is cleaned, iv) the feed efficiency, and v) how litter is stored, handled and applied (Gaskin et al., 2010). These factors substantially affect the amount of nutrients available to plants and the effectiveness of using broiler litter as a fertilizer substitute for crop production. Furthermore, the effectiveness of litter application depends on a series of careful farm operations such as: i) adequate analysis of available soil nutrients and pH levels, ii) prior knowledge of the nutrient requirements and removal rates of crops to be planted, iii) analysis of available nutrient in litter to be applied, and iv) adequate knowledge of state regulations regarding the application of these nutrients to the soil. Manure application is often based on the nitrogen requirement of the crop to be planted, as this is usually the most significant measure in the analysis mentioned above. However, due to the relatively equivalent composition of nitrogen (N) and phosphorus (P) in broiler litter, there exists a tendency to over apply phosphorus which can quickly become an environmental problem when the excess applied phosphorus gets into surface and ground water channels impacting the quality of these water sources (Harmel, 2009).

SC ranks top 10 nationwide in broiler production with a total output of 243 million broilers in the 2017 calendar year (USDA/NASS, 2019) (Table 3). This generated an estimated 303,875 tons of broiler litter and presents an opportunity for farmers to use relatively affordable, nutrient rich broiler litter as a fertilization alternative in their operations. However, there is limited research regarding the profitability of such an alternative, and the potential environmental impact in SC. This thesis is an effort to cover this gap in the literature.

Table 2: Average Nutrient Content of Various Types of Broiler Litter.

Constituent	Broiler Litter (lbs./ton)	Boiler Cake (lbs./ton)
Nitrogen	72.00	46.00
Phosphorus as P_2O_5	69.00	53.00
Potassium as K_2O	46.00	36.00
Calcium	44.00	34.00
Magnesium	9.00	7.00
Sulfur	12.10	9.20
Manganese	0.71	0.69
Copper	0.53	0.41
Zinc	0.64	0.60

Source: Chastain, Camberato, and Skewes (2019).

Table 3: 10-year Distribution of Broiler production in Heads and Dollars, with Estimated Broiler Litter Production in South Carolina.

Year	Broiler Production (1000 Heads)	Broiler Production ($ 1000)	Estimated Litter Production (Tons)
2009	237,800	$821,213	297,250
2010	241,000	$877,640	301,250
2011	223,400	$810,601	279,250
2012	222,800	$863,972	278,500
2013	226,700	$1,063,845	283,375
2014	232,500	$1,140,385	290,625
2015	242,600	$1,008,960	303,250
2016	244,700	$919,832	305,875
2017	243,100	$1,020,419	303,875
2018	237,800	$1,028,768	297,250

Source: USDA/NASS (2019).

Note: Broiler litter production at 1.25 tons litter/1000 birds (Coelho, Michael and Kornegay, 1996)

To develop this study, a computer-based row-cropping sequence of Corn-Wheat-Soybean over a 10-year period (2002-2011) was adopted, with each sequence occurring over a period of two years. The cropping sequence was modeled on the crop production data of the upper coastal region of South Carolina. This region was selected because it falls within the Eastern, Central and Southern agricultural districts of the state and accounts for the largest concentration of poultry and crop production activities. Specifically, the region accounts for a combined average of 89.95% of the state's production of broiler, corn, wheat and soybean production, with individual proportions of 75.36%, 98.79%, 88.94%, and 96.72% respectively (Table 4).

The row-cropping sequence was designed to represent an optimal production system. A system that intensively manages small grains (corn and wheat) followed by high-yielding soybean. This results in greater profitability and more efficient use of land, labor, equipment, inputs and having a beneficial effect on the environment by preventing runoff, mining leached nutrients and improve soil quality (Holshouser, AgFax 2017).

Double cropping is defined as a form of intensifying the use of existing cropland, by planting two different crops in the same field within a single year, with winter wheat and soybeans being the most common double cropped acres adopted in row crop farming. The greatest amount of double cropping in the United States is practiced in the southeastern states, accounting for roughly one third of the total U.S double-cropped acreage (an average of 2.7 million acres) (Borchers et al, 2014). Double cropping has been identified as a preferred production practice due to the cost saving advantages of the cultivation process. Furthermore, it results in resource efficiency, especially labor, machinery and other inputs, due to combining the production activities of both crops (Holshouser, AgFax 2017). Research also supports the viability of this process and favors the use of poultry litter over commercial inorganic fertilizer in row crop production activities that adopt double cropping, with reported improved crop yields of 74% to 97% higher for double cropped soybean on poultry litter plus supplementary commercial inorganic fertilizer and increased profitability for farms incorporating a mix of commercial inorganic fertilizer and broiler litter (a by-product of poultry production) when compared to using only commercial inorganic fertilizer (Harmel, Harmel and Patterson, 2008; Lin et al. 2019).

Table 4: Production Estimates of Broiler, Corn, Wheat, and Soybean in South Carolina by Agricultural District, 2017.

Agricultural District	Corn		Wheat [2]		Soybeans		Broiler Production (Head)	Percentage of Total Broiler Production (%)	Estimated Litter Production (Tons)
	Acre Planted	Percentage (%)	Acre Planted	Percentage (%)	Acre Planted	Percentage (%)			
Central	149,000	42.16	13,700	21.96	102,500	28.27	79,545,690	34.13	99,432
Eastern	136,000	38.48	24,100	38.62	210,200	57.97	28,353,500	12.17	35,441
North Central	5,100 [2]	1.44	3,000	4.81	5,200	1.43	1,450,000	0.62	1,812
North Western	4,290 [2]	1.21	6,900	11.06	11,900	3.28	57,412,252	24.64	71,765
Southern	43,500	12.31	6,100	9.78	26,800	7.39	9,226,292	3.96	11,532
West Central	15,500	4.39	8,600	13.78	6,000	1.65	57,057,993	24.48	71,322
State Total	353,390	100	62,400	100	362,600	100	233,045,727	100	291,307

Sources: (USDA/NASS, 2017)
[1] Broiler litter production at 1.25 tons litter/1000 birds (Coelho, Michael and Kornegay, 1996)
[2] Data reported for 2016 (USDA/NASS, 2016)

Objectives of Study

This research aims to evaluate the economic impact of four fertilization practices which differ in management levels, for a representative 1000-acre grain farm in SC. The four fertilization scenarios/practices examined are: i) a standard commercial inorganic fertilization practice supplying all required plant nutrients based on individual nutrient requirements (N, P, K) of corn and wheat (Option 1), ii) a broiler litter only fertilization practice under which plant nutrients are supplied solely from broiler litter based on the nitrogen needs of corn and wheat (Option 2), iii) a fertilization practice applying 2 tons per acre broiler litter annually plus supplementary commercial inorganic fertilizer (Option 3), and iv) a fertilization practice applying 2-tons per acre broiler litter every other year plus, supplementary commercial inorganic fertilizer with the broiler litter applied on the crop (corn) likely to utilize all or most of the nutrients supplied by litter (Option 4).

The study results have the potential to i) improve the way grain crops are grown in South Carolina, ii) increase the adoption of broiler litter for crop production, thereby creating a market for broiler litter generated yearly from the growing poultry industry within the state, iii) reduce on-farm input costs, potentially improving the profitability of respective farms who adopt it, and iv) boost the income of the state through increased taxes from farm operations or potential levies from violating established environmental pollution limits.

CHAPTER 2

LITERATURE REVIEW

Poultry Litter as an Alternate/Compliment Nutrient Source for Crop Production

Commercial inorganic fertilizers are inorganic chemicals which promote plant growth by enhancing the supply of essential nutrients (Porteous, 1996). They usually contain only a few nutrients – generally nitrogen, phosphorus, potassium, sulfur and sometimes micronutrients, either singly or combined and are readily available to plants once applied (Penhallegon, 2005). However, since they are lost from the soil quickly, re-fertilization often occurs during a growing season and these expenses can quickly add up, thereby increasing total on-farm costs for a farm operator. Alternatives or compliments to the use of commercial inorganic fertilizer to improve profitability and yield in row-cropping practices have been evaluated over the years, with poultry litter being identified as an appropriate less expensive option, due to its rich essential nutrient composition and high organic matter composition (Espinoza et al., 2019).

To evaluate the viability of using poultry litter as a nutrient source, researchers have conducted both field and computer-based experiments using various hybrid poultry litter and supplemental inorganic fertilizer mixtures (Almaz et al. 2017; Harmel, Harmel and Patterson, 2008; Lin et al. 2019) to determine the optimal application rate, that both improves economic and environmental efficiency. Row-crop rotations such as the corn-corn-wheat rotation and wheat-soybean rotation are some of the most common row-crop rotation practices adopted when utilizing poultry litter along with commercial inorganic fertilizer (Harmel, Harmel and Patterson, 2008; Lin et al. 2019; Watts and Torbert. 2011).

The manure application is most likely to be profitable on farms with a manure source that contains a relatively high nutrient concentration, applied to fields near the operations and to a crop or crop rotation that can fully utilize all the applied nutrients (Lory and Massey, 2006). It can also be utilized on mono-cropped field crops. However, Lin et al (2019) showed that improved yields were obtained for double cropped wheat-soybean when poultry litter is utilized, with recorded yield estimates 74% to 97% higher for double cropped soybean on poultry litter plus supplementary commercial inorganic fertilizer practice.

There has been an increased effort to attain a maximum utilization of poultry litter produced across the major poultry producing states in the United State of America. This has resulted in an increase in research into the economic viability of using poultry litter as a nutrient source. Economic analysis studies on poultry litter utilization compared to commercial inorganic fertilizer cover a broad range of indexes used to evaluate and determine optimal conditions for poultry litter fertilization adoption. Some of the documented studies include examination of the profitability and yield of alternative fertilization strategies (Harmel, Harmel and Patterson, 2008); evaluation of the profitability, breakeven cost and distances for transporting poultry litter over long distances to increase adoption in Virginia (Pelletier et al, 2001); and evaluation of the viability of a poultry litter for corn exchange program to increase adoption of poultry litter in Virginia (Pelletier, Ann and Kenyon, 2000).

Harmel, Harmel and Patterson (2008) recorded an average fertilizer cost of $56/acre for the control site (commercial fertilization only), which was not significantly different from the 2-ton litter/acre ($63/acre cost) and 3-tons litter/acre ($77/acre cost) litter rates, but was significantly less for sites with 4-ton litter/acre ($95/acre cost), 5-ton litter/acre ($108/acre cost), and 6-ton litter/acre ($120/acre cost) application rate per site, showing that the lower litter (1.5-2 ton/acre)/supplemental nitrogen and conventional commercial inorganic fertilizer were lower-cost fertilization practices. The litter application rate is consistent with the finding in Alabama by Lin et al (2019) who recorded improved yields for a wheat-soybean double cropping practice implementing an application rate of 1.3-ton litter/acre with supplemental inorganic N resulting in better income and crop yield.

With the aim of optimizing poultry litter fertilization, regulatory bodies have proposed alternative application strategies that apply litter based on the phosphorus requirement of the field crop being produced, with some state regulators insisting this approach be used if poultry litter is to be adopted. Paudel et al (2002) evaluated the cost-efficient management of broiler litter in the Alabama crop production scene, using a phosphorus litter application rule (defined as the application of litter based on the Cooperative Extension Service's phosphorus recommendation rate for a given crop in the region). The analysis which focused on corn, found the broiler litter-chemical fertilizer and broiler fertilizer options cost to be 37% and 21% less than the cost of using only chemical fertilizer, when all NPK equality constraints were imposed, and a combined state level savings of $97million dollars was realized for all crops evaluated. These result is consistent with savings observed when a similar fertilization approach was studied in Virginia, with a reduction in fertilizer cost when a phosphorus-based application plus supplemental inorganic potash and nitrogen gave a 35% reduction in cost when compared to commercial inorganic fertilizer application (Pelletier et al. 2001).

In summary, both Harmel, Harmel and Patterson (2008) and Lin et al (2019) identified an optimal application rate in the 1-2-ton litter/acre for applications based on the nitrogen requirements of the crops evaluated while Paudel et al (2002) and Pelletier et al. (2001), found an application rate based on the phosphorus requirements of the crop to be the optimal application principle. Both studies achieved efficient economic and environmental outcomes by reducing excess application of nutrients and fertilizer cost. The poultry litter was used in combination with commercial inorganic fertilizers to attain respective optimality conditions.

CHAPTER 3

METHODS AND DATA

The economic analysis conducted on each of the four fertilization practices, utilized: i) modified enterprise budgets used to estimate: variable cost, fixed cost, revenue, break-even price, break-even yield, and fertilizer costs for each of the fertilization scenarios, and ii) sensitivity analysis using variable yield, fertilizer input and historic commodity/produce prices for each fertilization scenarios. A Monte Carlo simulation was used to simulate variable yields along with historic fertilizer and commodity prices to mirror realistic changes in yield and prices that can be expected in stochastic economic conditions. Nutrient accumulation for each fertilization scenario was also evaluated by tracking excess nutrients applied within each fertilization scenario throughout the 10-year cropping sequence.

Representative Farm

The representative farm was a 1000-acre farm in the Upper Coastal Region of South Carolina, with medium soil fertility profile. A row-cropping sequence of corn-wheat -soybean with each complete sequence occurring over a period of two years and a total of five sequences for each fertilization scenario. The farm is computer-based, using historical data and trends with no field experiments.

In an email correspondence with Clemson extension agents Mr. J. Croft and Mr. A. Crouch on April 5, 2019, I obtained the crop planting and harvest data for the Upper Coastal Plain of South Carolina and used this information to create an optimum production schedule for the three crops. This was designed to account for time required to successfully plant, apply fertilizers and harvest crops in the most cost-effective manner (Table 5).

Table 5: Cropping Sequence Schedule Utilized in the Study.

ROTATION	MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1	TRANS		C_{EP}	C_{LP}	C	C	C	C_{EH}	C_{LH}	TRANS	W_{EP}	W_{EP}
	2	W	W	W	W	S_{EP}	S_{LP}	S	S	S_{LH}	S_{LH}	S_{LH}	TRANS
						W_{MH}	W_{MH}						
2	3	TRANS		C_{EP}	C_{LP}	C	C	C	C_{EH}	C_{LH}	TRANS	W_{EP}	W_{EP}
	4	W	W	W	W	S_{EP}	S_{LP}	S	S	S_{LH}	S_{LH}	S_{LH}	TRANS
						W_{MH}	W_{MH}						
3	5	TRANS		C_{EP}	C_{LP}	C	C	C	C_{EH}	C_{LH}	TRANS	W_{EP}	W_{EP}
	6	W	W	W	W	S_{EP}	S_{LP}	S	S	S_{LH}	S_{LH}	S_{LH}	TRANS
						W_{MH}	W_{MH}						
4	7	TRANS		C_{EP}	C_{LP}	C	C	C	C_{EH}	C_{LH}	TRANS	W_{EP}	W_{EP}
	8	W	W	W	W	S_{EP}	S_{LP}	S	S	S_{LH}	S_{LH}	S_{LH}	TRANS
						W_{MH}	W_{MH}						
5	9	TRANS		C_{EP}	C_{LP}	C	C	C	C_{EH}	C_{LH}	TRANS	W_{EP}	W_{EP}
	10	W	W	W	W	S_{EP}	S_{LP}	S	S	S_{LH}	S_{LH}	S_{LH}	TRANS
						W_{MH}	W_{MH}						

Table 4 Key:

C	Corn
W	Wheat
S	Soybean
TRANS	Transition period between crops
C_{LP}, C_{EH}	Corn planted late March and harvested early August
C_{EP}, C_{LH}	Corn planted early April and harvested late September
W_{EP}, W_{MH}	Wheat planted early November and harvested mid-May
W_{EP}, W_{MH}	Wheat planted early December and harvested mid-June
S_{EP}, S_{LH}	Soybean planted early May and harvested late September through October
S_{LP}, S_{LH}	Soybean planted late June and harvested late November through December

Based on recommendations in the Nutrient management guide for South Carolina (EC 476) (Franklin and Moore, 2001) and in consultation with Dr John Chastain on April 5, 2019[1], the following assumptions were implemented: i) a medium soil fertility profile was adopted and maintained throughout the study. A medium soil fertility soil has established phosphorus and

[1] Dr John Chastain- Professor and Extension Agricultural Engineer, Clemson University.

potassium levels, with phosphorus levels in the 30-61 lbs./acre range and recommendations for potassium application to be decreased by one-fourth of plant required potassium (Franklin and Moore, 2001). However, the study will adopt an application rate of 180% above the recommended potassium for wheat to enable us carry-over enough nutrients for the following soybean crop. ii) nitrogen was applied based on total crop nutrient requirements each year with no carry-over effect taken into consideration and served as the reference nutrient for litter application because it's the most volatile of nutrients and the slightest reduction of nutrient required for crop growth could significantly reduce crop yield for the production year. iii) no nutrient is applied on soybean due to potassium and phosphorus nutrients carried over in the soil from previous corn and wheat crops, and the fact that soybean is a legume with an ability to fix its own nitrogen, iv) all macronutrients (except nitrogen, phosphorus and potassium) and micronutrients were assumed to be available, therefore cost estimations will not be made on them, v) all broiler litter application is incorporated and not surface spread thereby increasing plant available nitrogen for crop growth, vi) no loss of potassium from root zone by downward movement of water, and vii) the assumption of no accounts for phosphorus applied that will be converted to organic forms through reaction with metals like aluminum and iron from Dr J. Chastain on December 4, 2019.

Nutrient Movement Through the Simulation Cycle

To track the movement of nutrients through each rotation-period and determine the optimum management system in terms of efficient input utilization, I used the nutrient accumulation and removal of crops (Table 6), the nutrient composition in broiler litter (Table 2) and projected yield estimates for each crop grown in the upper coastal region of the state (Table 7).

The required quantity of nitrogen, phosphorus, and potassium to grow a bushel of corn, wheat, and soybeans are reported in Table 6. These estimates are further broken down to show nutrients retained on the field after harvest (in the form of stovers) and nutrients taken away from the field through grain harvest. The yield average for the region are presented in Table 7 and represent an average range of recent crop yield provided by Clemson extension agent Mr. John Croft on May 9, 2019 through an email correspondence.

Information provided in Table 6 is essential for production planning, because it allows for the estimation of total nutrients required to attain average yield estimates and estimate nutrient removal through the grain and nutrients carried over through the stover for the corn-wheat-soybean cropping sequence in Upper Coastal Region of South Carolina (Table 8).

Table 6: Nutrient Removal by Crops Commonly Grown in South Carolina.

Crop	Plant part	N	P_2O_5	K_2O	Cu	Zn
		------------------pounds (lb.) of nutrients per bu------------				
Corn	Grain	0.67	0.35	0.25	0.02	0.10
	Stover	0.45	0.16	1.10	—	—
	Total Need	1.12	0.51	1.35	—	—
Soybean	Grain	3.27	0.73	1.2	0.03	0.10
	Stover	1.1	0.23	1.0	—	—
	Total Need	4.30	0.96	2.20	—	—
Wheat	Grain	1.16	0.41	0.24	0.02	0.13
	Stover	0.7	0.13	1.03	—	—
	Total Need	1.86	0.64	1.48	—	—

Source: Camberato (2016).

Table 7: Yield Averages for Selected Crops in the Upper Coastal Region of South Carolina

Crop	Corn[1]	Wheat	Soybeans
Practice	-----------Yield (Bushels/Acre) ------		
Irrigated[2]	200.00	80	65
Irrigated[2]	200.00	90	70
Average	200.00	85	67.5

Source: Email Correspondence Clemson Extension Agent Mr. J. Croft on July 9, 2019.

[1] Estimates obtained from personal interaction with extension professionals

[2] Irrigated production practice adopted for each estimate.

Table 8: Whole Crop Nutrient Requirements for Selected Crops Based on Yield Averages in Table 7.

Crop	Nutrient	Plant Need (lbs./bu)	Yield (bu)	Total Nutrient Requirement (lb/acre)
Corn	Nitrogen	1.12	200.00[1]	224.00
	Phosphorus	0.51		102.00
	Potassium	1.35		270.00
Wheat	Nitrogen	1.86	85.00[1]	158.10
	Phosphorus	0.64		54.40
	Potassium	2.66		226.44
Soybean	Nitrogen	4.37	68.00[1]	297.16
	Phosphorus	0.97		65.96
	Potassium	2.20		149.60

[1] Irrigated yield estimates.

The nutrient movement throughout the study for the different scenarios examined is depicted in Tables 9-12. Table 9 shows the nutrient movement for a strictly commercial inorganic fertilizer application and tracks the nutrient carry-over which is neglected by the operator when making subsequent applications. Table 10 shows the nutrient movement for the broiler litter only application scenario, which essentially uses 6 tons of broiler litter per acre to provide the necessary nitrogen required for corn, and 4 tons of broiler litter per acre to provide the required nitrogen for wheat. Quick accumulation of phosphorus and potassium is also observed in this scenario as we move from the first rotation to the fifth. The carry-over of nutrient from one crop to the next is computed as:

$$C_{mj} = CF_{mj} + PL_{mj} - R_{mj} \qquad (1.0)$$

$where,$

$C_{mj} = nutrient\ j, carried\ over\ from\ crop\ m\ (lbs\ per\ acre),$

$CF_{mj} = nutrient\ j, supplied\ from\ commercial\ inorganic\ fertilizer\ for\ crop\ m\ ,$

$PL_{mj} = nutrient\ j, supplied\ from\ broiler\ litter\ for\ crop\ m,$

$R_{mj} = nutrient\ j, removal\ by\ crop\ m,$

$m = type\ of\ crop, 1\ for\ corn, 2\ for\ wheat\ and\ 3\ for\ soybean$

$j = nutrient\ type, 1\ for\ nitrogen, 2\ for\ phosphorus\ and\ 3\ for\ potassium$

The last two scenarios follow the same application and nutrient tracking principle, except for the frequency of applying broiler litter. A yearly 2-ton per acre broiler litter application is examined in Table 11. In this option, even with the operator adjusting for carried-over nutrients from previous planting periods, a sharp rise in phosphorus accumulation is observed as the rotation progresses. Table 12 shows a more conservative application approach of broiler litter every other year at the 2-ton broiler litter per acre rate and on the crop that will most likely use up all or most of the broiler litter nutrients (corn). This results in better management of phosphorus levels over the rotation period and hence a more environmentally friendly application principle.

Table 9: Nutrient Distribution Spreadsheet for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using Only Commercial Inorganic Fertilizer.

Year	Year 1			Year 2								Year 3				Year 4							
Crop	Corn			Wheat				Soybean				Corn				Wheat				Soybean			
	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	224.00	—	90.00	—	158.10	—	59.50	—	—	—	74.80	—	224.00	—	90.00	—	158.10	—	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	102.00	—	32.00	70.00	54.40	—	13.60	110.80	—	—	15.64	95.16	102.00	—	32.00	165.16	54.40	—	13.60	205.96	—	—	15.64
K_2O (lbs/acre)	270.00	—	220.00	50.00	226.44	—	102.00	174.44	—	—	68.00	106.44	270.00	—	220.00	156.44	226.44	—	102.00	280.88	—	—	68.00

Year	Year 5				Year 6								Year 7				Year 8							
Crop	Corn				Wheat				Soybean				Corn				Wheat				Soybean			
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	—	224.00	—	90.00	—	158.10	—	59.50	—	—	—	74.80	—	224.00	—	90.00	—	158.10	—	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	190.32	102.00	—	32.00	260.32	54.40	—	13.60	301.12	—	—	15.64	285.48	102.00	—	32.00	355.48	54.40	—	13.60	396.28	—	—	15.64
K_2O (lbs/acre)	212.88	270.00	—	220.00	262.88	226.44	—	102.00	387.32	—	—	68.00	319.32	270.00	—	220.00	369.32	226.44	—	102.00	493.76	—	—	68.00

Year	Year 9				Year 10								Excess Nutrient
Crop	Corn				Wheat				Soybean				
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	
N (lbs/acre)	—	224.00	—	90.00	—	158.10	—	59.50	—	—	—	74.80	
P_2O_5 (lbs/acre)	380.64	102.00	—	32.00	450.64	54.40	—	13.60	491.44	—	—	15.64	475.80
K_2O (lbs/acre)	425.76	270.00	—	220.00	475.76	226.44	—	102.00	600.20	—	—	68.00	532.20

Notes: Nutrients applied based on recommended nitrogen, phosphorus and potassium required for corn and wheat production.
Crop nutrient removal rates aren't taking into consideration, therefore carry-over from previous crops is not considered.

Key for tables 9-12	
C	Nutrient carried over from previous crop
CF	Nutrient supplied from commercial inorganic fertilizer
PL	Nutrient supplied from broiler litter
R	Nutrient removed by harvested crop

Table 10: Nutrient Distribution Spreadsheet for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using Broiler Litter Only.

Year	Year 1			Year 2								Year 3				Year 4							
Crop	Corn			Wheat				Soybean				Corn				Wheat				Soybean			
	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	228.00	—	90.00	—	152.00	—	59.50	—	—	—	74.80	—	228.00	—	90.00	—	152.00	—	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	396.00	—	32.00	364.00	264.00	—	13.60	614.40	—	—	15.64	598.76	396.00	—	32.00	962.76	264.00	—	13.60	1213.16	—	—	15.64
K_2O (lbs/acre)	342.00	—	220.00	122.00	228.00	—	102.00	248.00	—	—	68.00	180.00	342.00	—	220.00	302.00	228.00	—	102.00	428.00	—	—	68.00

Year	Year 5				Year 6								Year 7				Year 8							
Crop	Corn				Wheat				Soybean				Corn				Wheat				Soybean			
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	—	228.00	—	90.00	—	152.00	—	59.50	—	—	—	74.80	—	228.00	—	90.00	—	152.00	—	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	1197.52	396.00	—	32.00	1561.52	264.00	—	13.60	1811.92	—	—	15.64	1796.28	396.00	—	32.00	2160.28	264.00	—	13.60	2410.68	—	—	15.64
K_2O (lbs/acre)	360.00	342.00	—	220.00	482.00	228.00	—	102.00	608.00	—	—	68.00	540.00	342.00	—	220.00	662.00	228.00	—	102.00	788.00	—	—	68.00

Year	Year 9				Year 10								Excess Nutrient
Crop	Corn				Wheat				Soybean				
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	
N (lbs/acre)	—	228.00	—	90.00	—	152.00	—	59.50	—	—	—	74.80	
P_2O_5 (lbs/acre)	2395.04	396.00	—	32.00	2759.04	264.00	—	13.60	3009.44	—	—	15.64	2993.80
K_2O (lbs/acre)	720.00	342.00	—	220.00	842.00	228.00	—	102.00	968.00	—	—	68.00	900.00

Notes: Broiler litter is applied based on the nitrogen requirements of corn and wheat.
The farm operator typically owns a broiler farm and litter is applied directly from the barn, thereby incurring only a litter spreading cost.
Crop nutrient removal rates aren't taking into consideration, therefore carry-over from previous crops is not considered.

Table 11: Nutrient Distribution Spreadsheet for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using 2-ton/acre Broiler Litter on Corn and Wheat plus Supplementary Commercial Inorganic Fertilizer.

Year	Year 1			Year 2								Year 3				Year 4							
Crop	Corn			Wheat				Soybean				Corn				Wheat				Soybean			
	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	76.00	148.00	90.00	—	76.00	82.10	59.50	—	—	—	74.80	—	76.00	148.00	90.00	—	76.00	82.10	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	132.00	—	32.00	100.00	132.00	—	13.60	218.40	—	—	15.64	202.76	132.00	—	32.00	302.76	132.00	—	13.60	421.16	—	—	15.64
K_2O (lbs/acre)	114.00	156.00	220.00	50.00	114.00	62.44	102.00	124.44	—	—	68.00	56.44	114.00	99.56	220.00	50.00	114.00	62.44	102.00	124.44	—	—	68.00

Year	Year 5				Year 6								Year 7				Year 8							
Crop	Corn				Wheat				Soybean				Corn				Wheat				Soybean			
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	—	76.00	148.00	90.00	—	76.00	82.10	59.50	—	—	—	74.80	—	76.00	148.00	90.00	—	76.00	82.10	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	405.52	132.00	—	32.00	505.52	132.00	—	13.60	623.92	—	—	15.64	608.28	132.00	—	32.00	708.28	132.00	—	13.60	826.68	—	—	15.64
K_2O (lbs/acre)	56.44	114.00	99.56	220.00	50.00	114.00	62.44	102.00	124.44	—	—	68.00	56.44	114.00	99.56	220.00	50.00	114.00	62.44	102.00	124.44	—	—	68.00

Year	Year 9				Year 10								Excess Nutrient
Crop	Corn				Wheat				Soybean				
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	
N (lbs/acre)	—	76.00	148.00	90.00	—	76.00	82.10	59.50	—	—	—	74.80	—
P_2O_5 (lbs/acre)	811.04	132.00	—	32.00	911.04	132.00	—	13.60	1029.44	—	—	15.64	1013.80
K_2O (lbs/acre)	56.44	114.00	99.56	220.00	50.00	114.00	62.44	102.00	124.44	—	—	68.00	56.44

Notes: Nutrients are applied using 2-ton per acre broiler litter on corn and wheat plus commercial inorganic fertilizer to make up for any additional nitrogen, phosphorus and potassium required for corn, wheat and soybean production.
Crop nutrient removal rates are taking into consideration, with nutrient application for subsequent years adjusted accordingly.
The farm operator typically buys litter from a litter broker, therefore pays full price for both litter purchase and spread.

Table 12: Nutrient Distribution Spreadsheet for a Row-cropping Sequence of Corn-Wheat-Soybean over a 10-year Period Using 2-ton/acre Broiler Litter on Corn Only plus Supplementary Commercial Fertilizer.

Year	------------Year 1---------------			--Year 2--								-----------------Year 3----------------				---Year 4---							
Crop	Corn			Wheat				Soybean				Corn				Wheat				Soybean			
	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	76.00	148.00	90.00	—	158.10	—	59.50	—	—	—	74.80	—	76.00	148.00	90.00	—	158.10	—	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	132.00	—	32.00	100.00	—	—	13.60	86.40	—	—	15.64	70.76	132.00	—	32.00	170.76	—	—	13.60	157.16	—	—	15.64
K_2O (lbs/acre)	114.00	156.00	220.00	50.00	176.44	—	102.00	124.44	—	—	68.00	56.44	114.00	99.56	220.00	50.00	176.44	—	102.00	124.44	—	—	68.00

Year	----------------Year 5-------------				---Year 6--								----------------Year 7-------------				---Year 8--							
Crop	Corn				Wheat				Soybean				Corn				Wheat				Soybean			
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R
N (lbs/acre)	—	76.00	148.00	90.00	—	158.10	—	59.50	—	—	—	74.80	—	76.00	148.00	90.00	—	158.10	—	59.50	—	—	—	74.80
P_2O_5 (lbs/acre)	141.52	132.00	—	32.00	241.52	—	—	13.60	227.92	—	—	15.64	212.28	132.00	—	32.00	312.28	—	—	13.60	298.68	—	—	15.64
K_2O (lbs/acre)	56.44	114.00	99.56	220.00	50.00	176.44	—	102.00	124.44	—	—	68.00	56.44	114.00	99.56	220.00	50.00	176.44	—	102.00	124.44	—	—	68.00

Year	----------------Year 9-------------				---Year 10---								Excess Nutrient
Crop	Corn				Wheat				Soybean				
	C	CF	PL	R	C	CF	PL	R	C	CF	PL	R	
N (lbs/acre)	—	76.00	148.00	90.00	—	158.10	—	59.50	—	—	—	74.80	
P_2O_5 (lbs/acre)	283.04	132.00	—	32.00	383.04	—	—	13.60	369.44	—	—	15.64	353.80
K_2O (lbs/acre)	56.44	114.00	99.56	220.00	50.00	176.44	—	102.00	124.44	—	—	68.00	56.44

Notes: Nutrients are applied using 2-ton per acre broiler litter on corn only plus commercial fertilizer to make up for any additional nitrogen, phosphorus and potassium required for corn, wheat and soybean production. This means broiler litter is applied every other year. This is done to reduce the accumulation of nutrients resulting from a more frequent broiler application rate. Crop nutrient removal rates are taking into consideration, with nutrient application for subsequent years adjusted accordingly. The farm operator typically buys litter from a litter broker, therefore pays full price for both litter purchase and spread

Yield Multiplier

Assuming a constant yield is unrealistic for a 10-year study. A method to vary the yields is therefore required. To achieve a variable yield, the yield multiplier equation (2.0) for each crop was created. The formula (2.0) is used to compute the yield multiplier y_{mt} for each crop m in each year t was developed with the help of Dr J. Chastain on December 11, 2019. The formula allows variation in annual crop yield based on crop specific properties and prior crop production trends using the random number generator to calculate Z_{mt}. The randomly generated Z_{mt} value for each year t, allows us to create bounds tailored to specific crops, this way, the simulation will incorporate variable crop yields that are both realistic and cover a range of best- or worst-case crop production scenarios.

In determining the bounds to use for crops in this study, the 10-year historical dryland yield averages for corn, wheat and soybeans were used to compute the coefficients of variation 12.89%, 19.17% and 15.68% respectively (Table 13). The Z_{mt} bounds of (-2,1) are used for corn-wheat due to the likelihood of nitrogen being limited as a result of the inability to track the amount of available nitrogen in the soil at any one time. The high volatility of nitrogen coupled with the inability of these crops to make up for any nitrogen deficiencies will result in lower yields. For the soybean crop the bounds of (-2,2) used due to soybeans ability to fix its own nitrogen, resulting in greater likelihood that we will have sufficient nitrogen for crop growth to meet or exceed our yield goals with realistic estimates and any reduced yields will be due to either inadequate P-K, or extreme weather conditions such as hurricanes or heavy floods.

The yield multiplier was then simulated 1000 times using the monte-carlo process. The Monte-Carlo simulation creates a “what if” scenario analysis utilizing hundreds or thousands of possible iterations that continually vary the yield for respective years. This results in a better estimation of the true Net Present Value (NPV), determination of the probability of a negative NPV in a given analysis, and the likelihood of the true NPV exceeding a given desired value for all scenarios being analyzed (Lifland, 2015).

$$y_{mt} = 1 + \left(\frac{CV_m}{100}\right) Z_{mt} \tag{2.0}$$

$y_{mt} = calculated\ variable\ yield\ multiplier\ for\ crop\ m, in\ year\ t$

$CV_m = coefficient\ of\ variation\ for\ crop\ m$

$Z_{mt} = bounded\ random\ number\ for\ crop\ m, in\ year\ t,$ and

$m = \ crop\ planted, 1\ for\ corn, 2\ for\ wheat\ and\ 3\ for\ soybean.$

Table 13: Average Yearly Dryland Yield Estimates for Selected Crops, 2002-2012.

Year	Corn (bu/acre)	Wheat (bu/acre)	Soybean (bu/acre)
2002	97.00	37.00	23.00
2003	120.00	39.00	32.00
2004	130.00	44.00	37.00
2005	126.00	51.00	29.00
2006	115.00	50.00	34.00
2007	100.00	30.00	25.00
2008	85.00	54.00	36.00
2009	113.00	47.00	38.00
2010	112.00	36.00	29.00
2011	101.00	60.00	35.00
2012	134.00	53.00	39.00
Mean	112.09	45.55	32.45
Standard Deviation	14.45	8.73	5.09
Coefficient of Variation	12.89%	19.17%	15.68%

Source: USDA/NASS 2019.

Note: Coefficient of Variation computed as the ratio of the standard deviation and mean multiplied by 100.

$Calculating\ \ y_{mt}\ for\ a\ corn\ crop\ m = 1,$ in year $t = 1$, $CV_m = 12.89\%$ and a

$Z_{mt}\ upper\ bound\ of\ 1.$

$$y_{mt} = 1 + \left(\frac{12.89}{100}\right)(1) = 1.1289.$$

Enterprise Budget

An enterprise budget is a tool for estimating the cost and returns for farm activities. Each budget specifies a system of production, inputs required, and annual sequence of operations as well as summarizes the costs and returns associated with the activity (Damona and Roger, 2017). In creating the enterprise budgets used for each management system irrigated corn, wheat and soybean budgets from the Clemson University Extension Service were adopted (Clemson Extension Service, 2019). The budgets where modified with the addition of a broiler litter cost under the variable cost section (Appendix A1-4). Multiple budgets were combined to depict the cropping sequence in Table 5, along with the historic commodity and fertilizer prices for respective years (Tables 14 and 15 respectively) and the addition of a new subsection under each scenarios budget series that consolidated cashflows (total variable cost, total revenue, total fixed cost, and fertilizer cost) for the entire study period. Variable costs directly associated with this study are the fertilization cost per acre (purchase and application cost) for each fertilization scenario, seeds, chemicals, drying, irrigation, labor, interest on operating capital and hauling.

Tables 14 and 15, show the average commodity prices and commercial inorganic fertilizer (nitrogen, phosphorus and potassium) prices from 2002 to 2012. On the assumption the farmer is a profit maximizer, we included storage and drying costs in the individual crop enterprise budgets. Therefore, the farmer is expected to sell his produce the following year after harvest during months of higher grain prices.

Table 14: Average Yearly Agricultural Commodity Prices, 2002-2012.

Year	Corn ($/bu)	Wheat ($/bu)	Soybeans ($/bu)
2002	$2.70	$2.60	$5.60
2003	$2.70	$3.00	$7.60
2004	$2.30	$3.20	$5.60
2005	$2.19	$2.80	$5.55
2006	$2.98	$3.05	$6.80
2007	$3.88	$4.55	$10.90
2008	$4.59	$5.95	$9.00
2009	$3.86	$4.25	$9.50
2010	$5.49	$5.00	$11.80
2011	$6.60	$6.99	$12.00
2012	$7.50	$6.65	$14.50

Source: NASS/USDA, (2019).

Table 15: Historical Prices of Selected Plant Nutrient, 2002-2012.

Year	Urea 44-46% Nitrogen	Super-Phosphate 46% Phosphate	Potassium Chloride 60% Potassium
2002	$0.21	$0.24	$0.14
2003	$0.28	$0.26	$0.14
2004	$0.30	$0.29	$0.15
2005	$0.36	$0.33	$0.20
2006	$0.39	$0.35	$0.23
2007	$0.49	$0.45	$0.23
2008	$0.60	$0.87	$0.47
2009	$0.53	$0.69	$0.71
2010	$0.49	$0.55	$0.43
2011	$0.57	$0.69	$0.50

Source: USDA-ERS (2014).

[1]All prices in $/lb. of plant nutrient.

Net Present Value

In comparing each fertilization scenario, the 10-year profitability estimates and the determinant of the most viable management practice to adopt, the net present value (NPV) for each fertilization practice was calculated. Net Present Value (NPV) is the present value of cashflows over a period. It is used in capital budgeting to analyze the profitability of an investment or project (Benavidez, Anastasia, and David, 2019). A positive NPV value indicates an investment is profitable. This method of analysis enables the ranking of scenarios according to profitability and allows for better comparison between alternatives, especially in situations where estimates are relatively close, our choice will eventually be dependent on other factors such as the negative environmental impact of either one of the scenarios with similar outcomes. Equation (3.0) is used in computing NPV in this study, it is a combination of the yield multiplier in equation (2.0) and the standard NPV equation (Benavidez, Anastasia, and David, 2019).

$$NPV_f = \sum_{t=0}^{9} \frac{B_{mt}}{(1+i)^t} - \sum_{t=0}^{9} \frac{C_{tm}}{(1+i)^t} \qquad (3.0)$$

$where,$

$B_{tm} = P_{tm} * (\overline{Y_m} * y_m)$

$B_{tm} = Gross\ revenue\ during\ the\ period\ t, for\ crop\ m$

$C_{tm} = Cost\ of\ producing\ crop\ m, in\ period\ t$

$y_m = yeild\ multiplier\ for\ crop\ m$

$P_{mt} = commodity\ prices\ in\ period\ t, for\ crop\ m$

$\overline{Y_m} = average\ expected\ yeild\ of\ crop\ m\ grown\ in\ South\ Carolina$

$i = discount\ rate\ (assumed\ to\ be\ 7\%)$

$f = represents\ the\ fertilization\ scenario\ being\ examined\ (1\ commercial$

$inorganic\ fertilizer\ only, 2\ for\ broiler\ litter\ only, \ldots., 4)$

$t = number\ of\ time\ periods\ (0, 1, \ldots\ldots, 9)$

$m = crop\ planted, 1\ for\ corn, 2\ for\ wheat\ and\ 3\ for\ soybean$

CHAPTER 4

RESULTS AND DISCUSSIONS

Fertilizer Savings Analysis

Variable costs directly associated with this study are the fertilization costs per acre (purchase and application cost) for each fertilization scenario, seeds, chemicals, drying, irrigation, labor, land rent, interest on operating capital and hauling. A detailed comparison between the fertilizer cost of the control practice (commercial inorganic fertilizer only) and the various proposed alternatives utilizing either a combination of broiler litter and commercial inorganic fertilizer, or just the broiler litter as shown in Table 16. This comparison is done at the annual level and over the 10-year study period.

The commercial inorganic fertilizer scenario appears to be the most expensive, with a total fertilizer expenditure of $1,818.87/acre over the 10-year period while the broiler litter only option cost a fraction of this estimate, which is approximately 13.74% of the fertilizer cost for the control practice. These two scenarios account for the two extremes in the fertilizer cost analysis. The fertilization scenarios applying a mix of broiler litter and commercial inorganic fertilizer are respectively 28.89% and 28.25% less than the control practice's total fertilizer expenditure. The total fertilizer expenditure over the 10-year study period was $250.00/acre, $1,293.31/acre, and $1,304.95/acre for the broiler litter only fertilization scenario, the 2-ton per acre, per year broiler litter, plus supplementary commercial inorganic fertilizer, and the 2-ton/acre on corn only plus supplementary commercial inorganic fertilizer scenarios respectively. The broiler litter only scenario appears to be the most cost-effective scenario when the assumption of the farm operator incurring the broiler litter spreading cost holds. However, situations in which broiler litter is purchased at the market price of $60 for 2-ton broiler litter plus spreading on each acre, will increase the total fertilizer expenditure to $1500.00/acre. This will make the broiler litter only fertilization practice the second most expensive fertilization practice behind commercial inorganic fertilizer only practice, and third in terms of cost effectiveness behind the 2 ton/acre/year litter plus supplementary commercial inorganic fertilizer, and the 2 ton/acre on corn only plus supplementary commercial inorganic fertilizer scenarios.

Table 16: Economics of Using Broiler Litter as a Substitute for Commercial Inorganic Fertilizer for a Corn-Wheat-Soybean Cropping Sequence Production in South Carolina (Per Acre Farm Basis)

Year	Commercial Fertilizer Only	Broiler Litter only (1-2)		2-ton/acre Broiler Litter on Corn and Wheat plus Supplemental Commercial Fertilizer (1-4)		2-ton/acre Broiler Litter on Corn Only plus Supplemental Commercial Fertilizer (1-6)	
	Cost ($/Acre) (1)	Cost ($/Acre) (2)	Percent Change (3)	Cost ($/Acre) (4)	Percent Change (5)	Cost ($/Acre) (6)	Percent Change (7)
Y 1	$184.74	$50.00	-72.93%	$197.62	6.97%	$168.98	-8.53%
Y 2	$0.00	$0.00	0.00%	$0.00	0.00%	$0.00	0.00%
Y 3	$234.73	$50.00	-78.70%	$213.47	-9.06%	$193.46	-17.58%
Y 4	$0.00	$0.00	0.00%	$0.00	0.00%	$0.00	0.00%
Y 5	$318.38	$50.00	-84.30%	$247.39	-22.30%	$243.23	-23.60%
Y 6	$0.00	$0.00	0.00%	$0.00	0.00%	$0.00	0.00%
Y 7	$597.35	$50.00	-91.63%	$333.79	-44.12%	$372.69	-37.61%
Y 8	$0.00	$0.00	0.00%	$0.00	0.00%	$0.00	0.00%
Y 9	$483.67	$50.00	-89.66%	$301.04	-37.76%	$326.59	-32.48%
Y 10	$0.00	$0.00	0.00%	$0.00	0.00%	$0.00	0.00%
Total Fertilizer Expenditure	$1,818.87	$250.00	-86.26%	$1,293.31	-28.89%	$1,304.95	-28.25%

Note: Costs for years 1,3,5,7 and 9 represents the sum of fertilizer cost for corn and wheat, while the cost for years 2,4,6,8,10 are for soybean fertilizer cost which are zero, due to the assumption that soybean fixes its own nitrogen nutrient and enough carried over potassium and phosphorus will be available in the soil for the soybean crop.

Net Present Value Analysis

The monte-carlo simulation evaluated the NPV of cashflows for all four fertilization scenarios under two net income cases; i) the net income above total cost, and ii) net income above variable cost. Under the net income above total cost evaluation, the commercial inorganic fertilization scenario (option 1) was observed to be the least profitable ($1,651,317 in losses) compared to the three alternative fertilization practices incorporating broiler litter (options 2-4). Negative mean NPV values for options 2,3 and 4 are also observed (Table 17). For the 1000 iterations, the monte-carlo distribution estimated negative NPV values for the commercial inorganic fertilization scenario (option 1), with approximately 100.00% of the simulated net present values falling below $0.00 and a similar trend observed for the options 2, 3, and 4 (Table 17).

For the income above variable cost evaluation, results show that all scenarios had a positive mean value of $386,141/acre, $1,511,052/acre, $750,986/acre, and $745,594/acre for option 1, 2, 3 and 4 respectively after 1000 iterations (Table 18). This difference in mean net present values between practices can be linked to the cost incurred due to the fertilization practice adopted by the farmer, with the broiler litter farmer experiencing the highest mean NPV due to its relatively low fertilization cost as seen in Table 16. However, the difference in mean NPV values between the two income cases evaluated can be linked to the fixed costs of respective practices. For the 1000 iterations, fertilization options 2, 3 and 4 all had positive mean NPV values except for the commercial fertilizer only practice (option 1) who had 1% of its simulated NPV values fall below $0.00, an indication that this practice is more risky and careful consideration should be taken before adopting the practice. We observed a similar standard deviation for all scenario deviations because, each fertilization scenario examines the same farmer over the same period of time, with the same prices, yield estimates, and relatively similar variable costs, but differ on the fertilization practices. This will result in a similar variation in NPV values but shifts in profitability will be associated to the changing variable for all scenarios (this is the cost of fertilizer).

Table 17: Summary Statistics of NPV of Net Income using the Monte-Carlo Simulation for all Four Scenarios.

Fertilization Scenario	Mean ($)	Standard Deviation	Minimum ($)	Maximum ($)	Probability NPV < 0	Confidence Interval	
						Lower Limit	Upper Limit
Option 1	-$1,651,317	$141,039.66	-$2,107,853	-$1,200,496	100%	-$1,660,058	-$1,642,575
Option 2	-$470,165	$141,039.01	-$926,684	-$19,347	100%	-$478,907	-$461,423
Option 3	-$1,268,235	$141,039.74	-$1,724,765	-$817,427	100%	-$1,276,977	-$1,259,494
Option 4	-$1,273,895	$141,039.71	-$1,730,427	-$823,089	100%	-$1,282,636	-$1,273,895

Table 18: Summary Statistics of NPV of Income Above Variable Cost using the Monte-Carlo Simulation for all Four Scenarios.

Fertilization Scenario	Mean ($)	Standard Deviation	Minimum ($)	Maximum ($)	Probability NPV < 0	Confidence Interval	
						Lower Limit	Upper Limit
Option 1	$386,141	$141,624.55	-$72,668	$839,050	1%	$377,364	$394,919
Option 2	$1,511,052	$141,624.04	$1,052,243	$1,963,957	0%	$1,502,274	$1,519,830
Option 3	$750,989	$141,624.27	$292,189	$1,203,890	0%	$742,211	$759,766
Option 4	$745,594	$141,624.19	$286,788	$1,198,489	0%	$736,816	$745,594

Key for Table 17 and 18	
Option 1	Commercial Fertilizer only
Option 2	Broiler Litter only
Option 3	2-ton/acre broiler litter on corn and wheat plus supplemental commercial fertilizer
Option 4	2-ton/acre broiler litter on corn only plus supplemental commercial fertilizer

Nutrient Analysis

A major constraint to the sole utilization of broiler litter to supply all plant nutrients is the risk of nutrients accumulation over periods of continuous applications, resulting in nutrients levels rising to harmful concentrations, which can have adverse effects on the environment particularly the quality of water supply around the application site. Although the broiler litter only fertilization scenario shows the largest cost savings among all four management practices examined (Table 16), there is a likelihood for higher nutrient accumulation over long periods.

Table 19 represents a summary of Tables 9-12 which tracks the likely nutrient accumulation of each fertilization practice over the 10-year period. In the absence of soil testing these results only provide an index of potential nutrient accumulation for each practice. Practices with greater nutrient accumulation in lbs per acre have a potential for environmental damage and indicate waste of nutrients by these practices. The practices with the greatest nutrient accumulation are the broiler litter only practice, and commercial inorganic fertilizer only practice.

In summary, phosphorus accumulation occurred in this order: broiler litter only > 2 ton/acre on corn and wheat plus commercial inorganic fertilizer > commercial inorganic fertilizer only > 2 ton/acre on corn only plus commercial inorganic fertilizer, with estimates of 2993.00, 1013.80, 475.80 and 353.80 lbs./acre concentrations respectively. While the potassium accumulation occurred in this order: broiler litter only > commercial inorganic fertilizer only > 2 ton/acre yearly plus commercial inorganic fertilizer = 2 ton/acre on corn only plus commercial inorganic fertilizer, with estimates of 900.00, 532.20 and 56.44 lbs./acre respectively.

Table 19: Likely Excess Nutrients Applied over the 10-year study Period under each Fertilization Scenario.

Management Option	Plant Nutrient	Excess (lbs./acre)	Excess (lbs./1000 acres)
Commercial Fertilizer Only	N	0	0
	P2O5	475	475,800
	K20	532	532,200
Broiler Litter only	N	0	0
	P2O5	2,993	2,993,800
	K2O	900	900,000
2 ton/acre broiler litter on corn and wheat plus supplementary commercial fertilizer	N	0	0
	P2O5	1,013	1,013,800
	K2O	56	56,440
2 ton/acre broiler litter on corn only plus supplementary commercial fertilizer	N	0	0
	P2O5	353	353,800
	K2O	56	56,440

CHAPTER 5

CONCLUSION

This thesis evaluated the economic impact of adopting broiler litter as a nutrient supplement for crop production in South Carolina by comparing four fertilization practices. The four fertilization practices examined are: i) a commercial inorganic fertilization practice applying nutrients based on individual nutrient needs of crops, ii) a broiler litter only fertilization practice under which plants nutrients are supplied solely from broiler litter based on the nitrogen needs of corn and wheat iii) a fertilization practice applying 2-tons per acre broiler litter annually plus supplementary commercial inorganic fertilizer and iv) a fertilization practice applying 2-tons per acre broiler litter applied every other year plus, supplementary commercial inorganic fertilizer with the broiler litter applied on the crop (corn) likely to utilize all or most of the nutrients supplied by litter. The analysis was computer based with no field experiments.

The study relied on previous literature evaluating the economic effects under different scenarios and cropping practices using actual experiment stations occuring over a period of time and computer simulated evaluations (Almaz et al. 2017; Harmel, Harmel and Patterson, 2008; Harmel et al. 2004; Harmel et al. 2009; He et al. 2009; Lin et al. 2019; Mcleod and Hegg 1984; Paudel and McIntosh, 2000; Ranatunga et al. 2013). An important consideration for evaluating the economic effect of adopting broiler litter on row crop production was the adoption of a double cropping system which significantly reduced the cost of the entire rotations being evaluated and, in some studies, improved crop yield (Harmel, Harmel and Patterson, 2008; Lin et al. 2019; Watts and Torbert. 2011).

The following resources were utilized to make these evaluations: i) data collected from agribusiness and extension professionals on fertilization practices, planting and harvesting dates, broiler litter pricing and yield estimates for the state of South Carolina, ii) historical price data for input and output variables (fertilizer and commodity) from national databases made publicly available by the USDA, iii) Clemson Extension Services Enterprise Budgets, and iv) financial tools (NPV and Monte-Carlo Simulation). These resources were combined to create row-cropping sequence, nutrient management and tracking spreadsheet, and create a yield multiplier to vary crop yields, each of which were essential to the success of the project.

Results showed that the broiler litter fertilization practice was the most profitable and least vulnerable for all economic parameters evaluated, while the commercial inorganic fertilization practice was the least profitable and most vulnerable to changing economic conditions. The observed trend is due to difference in fertilization cost, with the commercial inorganic scenario having the highest input expense from high inorganic fertilizer prices relative to the price of broiler litter. The commercial inorganic fertilizer was likely to record low net revenue under poor/good planting or environmental conditions.

However, the nutrient analysis showed that, the broiler litter only fertilization scenario had the greatest potential to accumulate high levels of phosphorus over the 10-year period. To address potential pollution concerns, the management options 3 and 4 were designed with the aim of managing the excess application of nutrients over extended periods by utilizing a combination of 2-tons of broiler litter per acre and supplementary commercial inorganic fertilizer to supply plant nutrients. The results showed significantly lower nutrient carry-over. Results from options 3 and 4 were also consistent with findings by Harmel, Harmel, and Patterson (2008) who found a system incorporating 2-tons of broiler litter per acre plus supplementary inorganic fertilizer to be both economically and environmentally efficient. A deterent to a practice using only broiler litter or commercial inorganic fertilizer which have the greatest excess nutrient accumulation over long periods will be increased levies or taxes, equivalent or greater than the profit farmers stand to realize from adopting such practices.

In summary, the study provided important information on crop production practices in South Carolina, with guidances on the adoption or changes in management practices showing their overall effect on farm economics and the environment. These findings can be summarized as follows

1. Broiler litter is a cost effective fertilization option for crop production
2. Broiler littter can reduce on-farm input cost and enhance profitability of the farm
3. A Broiler litter only fertilization practice is cost-effective, when broiler litter is sourced from a barn owned by the farm operator, but quickly drops in profitability only ahead of the commercial inorganic fertilizer only practice, when litter is purchased at the applicable market rates from litter broker.
4. A 2-ton broiler litter per acre on corn only plus commercial inorganic fertilizer is an optimal application principle for broiler litter usage with the least nutrient carry-over and favorable cost efficiency.

Future Research/Limitations

This study was conducted using simulations and historic data to estimate variable costs, revenue, fertilizer savings, while holding interest rates, machinery, and labor costs constant. This created constraints in performing analysis, as we could not model the study to include these dynamic variables. A field experiment will offer better estimates for analysis of parameters evaluated in this study and offer insight into other important activities that take place on the farm, such as actual yield responses of each of the crops in the sequence to the various management practices evaluated, changes in labour and machinery costs and other dynamic variables.

An additional management option may be included to better manage phosphorus accumulation in the soil. Recent studies and extension services recommend a broiler litter application based on the phospohorus requirement of the crop rather than the nitrogen requirement with increased nutrient utilization and better cost efficiency reported (Paudel et al., 2002).

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APPENDICES

Table A1. Clemson Extension Services Sample Enterprise Budget.

CORN FOR GRAIN - IRRIGATED - CONSERVATION TILLAGE

ESTIMATED COSTS AND RETURNS PER ACRE

200 BUSHEL YIELD, 80 ACRE CENTER PIVOT - 6" OF WATER

	UNIT	QUANTITY	PRICE OR COST/UNIT	COST OR REVENUE ($/ACRE)	YOUR FARM
1. GROSS RECEIPTS					
CORN	CORN	BU.	$200.00	$2.70	
TOTAL RECEIPTS:				$470.00	
2. VARIABLE COSTS					
SEED	THOU.	32.00	$3.48	$111.36	
FERTILIZER					
NITROGEN	LBS	210.00	$0.21	$44.10	
PHOSPHATE	LBS	80.00	$0.24	$19.20	
POTASH	LBS	60.00	$0.14	$8.40	
LIME (PRORATED)	LBS	0.50	$52.00	$26.00	
HERBICIDES	ACRE	1.00	$31.02	$31.02	
FUNGICIDES	ACRE	1.00	$36.84	$36.84	
INSECTICIDES	ACRE	1.00	$20.65	$20.65	
IRRIG., MACH & LABOR	ACRE	6.00	$8.00	$48.00	
1.0583 DRYING (3 POINTS)	BU.	211.66	$0.25	$52.92	
HAULING	BU.	200.00	$0.35	$70.00	
CROP INSURANCE	ACRE	1.00	$15.00	$15.00	
TRACTOR/MACHINERY	ACRE	1.00	$55.40	$55.40	
LABOR	HRS	2.77	$11.25	$31.16	
CROP SCOUTING	ACRE	1.00	$9.00	$9.00	
INTEREST ON OP. CAP.	DOL.	285.03	$0.07	$19.95	
TOTAL VARIABLE COSTS:				$599.00	
3. INCOME ABOVE VARIABLE COSTS:				-$59.00	
4. FIXED COSTS					
TRACTOR/MACHINERY	ACRE	1.00	$74.79	$74.79	
IRRIGATION	ACRE	1.00	$125.00	$125.00	
TOTAL FIXED COSTS:				$199.79	
5. OTHER COSTS					
LAND RENT	ACRE	1.00	$60.00	$60.00	
GENERAL OVERHEAD	DOL.	599.00	$0.05	$29.95	
TOTAL OTHER COSTS:				$89.95	
6. TOTAL COSTS:				$888.74	
7. NET RETURNS TO RISK AND MANAGEMENT:				-$348.74	

Table A2. Corn Enterprise Budget for 2-tons Broiler Litter per acre plus Supplementary Commercial Inorganic Fertilizer.

CORN FOR GRAIN - IRRIGATED - CONSERVATION TILLAGE

ESTIMATED COSTS AND RETURNS PER ACRE

200 BUSHEL YIELD, 80 ACRE CENTER PIVOT - 6" OF WATER

		UNIT	QUANTITY	PRICE OR COST/UNIT	COST OR REVENUE ($/ACRE)	COST OR REVENUE ($/1000 ACRE)
1. GROSS RECEIPTS						
	CORN	BU.	200.00	$2.70	$540.00	$540,000.00
	TOTAL RECEIPTS:				$540.00	$540,000.00
2. VARIABLE COSTS						
	SEED	THOU.	32.00	$3.48	$111.36	$111,360.00
	FERTILIZER					
	NITROGEN	LBS	148.00	$0.21	$30.73	$30,730.00
	PHOSPHATE	LBS	0.00	$0.24	$0.00	$0.00
	POTASH	LBS	156.00	$0.14	$21.32	$21,320.00
	LIME (PRORATED)	LBS	0.84	$0.03	$3.11	$3,108.00
	HERBICIDES	ACRE	1.00	$31.02	$31.02	$31,020.00
	FUNGICIDES	ACRE	1.00	$36.84	$36.84	$36,840.00
	INSECTICIDES	ACRE	1.00	$20.65	$20.65	$20,650.00
	IRRIG., MACH & LABOR	ACRE	6.00	$8.00	$48.00	$48,000.00
1.0583	DRYING (3 POINTS)	BU.	211.66	$0.25	$52.92	$52,920.00
	HAULING	BU.	200.00	$0.35	$70.00	$70,000.00
	CROP INSURANCE	ACRE	1.00	$15.00	$15.00	$15,000.00
	TRACTOR/MACHINERY	ACRE	1.00	$55.40	$55.40	$55,400.00
	LABOR	HRS	2.77	$11.25	$31.16	$31,160.00
	CROP SCOUTING	ACRE	1.00	$9.00	$9.00	$9,000.00
	INTEREST ON OP. CAP.	DOL.	$263.75	7%	$18.46	$18,460.00
	POULTRY LITTER	TON	2.00	$30.00	$60.00	$60,000.00
TOTAL VARIABLE COSTS:					$614.97	$614,968.00
3. INCOME ABOVE VARIABLE COSTS:					-$74.97	-$74,968.00
4. FIXED COSTS						
	TRACTOR/MACHINERY	ACRE	1.00	$74.79	$74.79	$74,790.00
	IRRIGATION	ACRE	1.00	$125.00	$125.00	$125,000.00
TOTAL FIXED COSTS:					$199.79	$199,790.00
5. OTHER COSTS						
	LAND RENT	ACRE	1.00	$60.00	$60.00	$60,000.00
	GENERAL OVERHEAD	DOL.	$614.97	$0.05	$30.75	$30,750.00
TOTAL OTHER COSTS:					$90.75	$90,750.00
6. TOTAL COSTS:					$905.51	$905,508.00
7. NET RETURNS TO RISK AND MANAGEMENT:					-$365.51	-$365,508.00

Table A3. Wheat Enterprise Budget for 2-tons Broiler Litter per acre plus Supplementary Commercial Inorganic Fertilizer.

WHEAT FOR GRAIN - CONSERVATION TILLAGE

ESTIMATED COSTS AND RETURNS PER ACRE
85 BUSHEL YIELD

	UNIT	QUANTITY	PRICE OR COST/UNIT	COST OR REVENUE ($/ACRE)	COST OR REVENUE ($/1000 ACRE)
1. GROSS RECEIPTS					
WHEAT	BU.	85.00	$3.00	$255.00	$255,000.00
TOTAL RECEIPTS:				$255.00	$255,000.00
2. VARIABLE COSTS					
SEED (CERTIFIED)	BU.	2.00	$18.25	$36.50	$36,500.00
FERTILIZER					
NITROGEN	LBS	158.10	$0.21	$32.82	$32,820.00
PHOSPHATE	LBS	0.00	$0.24	$0.00	$0.00
POTASH	LBS	176.44	$0.14	$24.11	$24,110.00
LIME (PRORATED)	LBS	0.84	$0.03	$3.32	$3,320.10
HERBICIDES	ACRE	1.00	$24.02	$24.02	$24,020.00
FUNGICIDES	ACRE	1.00	$18.42	$18.42	$18,420.00
INSECTICIDES	ACRE	1.00	$4.99	$4.99	$4,990.00
AERIAL APPLICATION	APPL	1.00	$10.00	$10.00	$10,000.00
HAULING	BU.	85.00	$0.35	$29.75	$29,750.00
TRACTOR/MACHINERY	ACRE	1.00	$46.07	$46.07	$46,070.00
LABOR	HRS	2.27	$11.25	$25.54	$25,540.00
INTEREST ON OP. CAP.	DOL.	$127.77	$0.07	$8.94	$8,940.00
POULTRY LITTER	TON	0.00	$10.00	$0.00	$0.00
TOTAL VARIABLE COSTS:				$264.48	$264,480.10
3. INCOME ABOVE VARIABLE COSTS:				-$9.48	-$9,480.10
4. FIXED COSTS					
TRACTOR/MACHINERY	ACRE	1.00	$60.66	$60.66	$60,660.00
IRRIGATION	ACRE	1.00	$60.00	$60.00	$60,000.00
TOTAL FIXED COSTS:				$120.66	$120,660.00
5. OTHER COSTS					
LAND RENT	ACRE	1.00	$60.00	$60.00	$60,000.00
GENERAL OVERHEAD	DOL.	$264.48	$0.05	$13.22	$13,220.00
TOTAL OTHER COSTS:				$73.22	$73,220.00
6. TOTAL COSTS:				$458.36	$458,360.10
7. NET RETURNS TO RISK AND MANAGEMENT:				-$203.36	-$203,360.10

Table A4. Soybean Enterprise Budget for 2-tons Broiler Litter per acre plus Supplementary Commercial Inorganic Fertilizer.

SOYBEANS - FULL SEASON, NO TILL (RR 2 XTEND), 30" ROWS
ESTIMATED COSTS AND RETURNS PER ACRE
68 BUSHEL ACTUAL YIELD.

	UNIT	QUANTITY	PRICE OR COST/UNIT	COST OR REVENUE ($/ACRE)	COST OR REVENUE ($/1000 ACRE)
1. GROSS RECEIPTS					
SOYBEANS	BU.	68.00	$5.60	$380.80	$380,800.00
TOTAL RECEIPTS:				$380.80	$380,800.00
2. VARIABLE COSTS					
SEED	140K	0.91	$65.00	$59.46	$59,460.00
FERTILIZER **					
PHOSPHATE	LBS	0.00	$0.60	$0.00	$0.00
POTASH	LBS	0.00	$0.33	$0.00	$0.00
LIME (PRORATED)	LBS	0.00	$52.00	$0.00	$0.00
HERBICIDES	ACRE	1.00	$54.20	$54.20	$54,200.00
INSECTICIDES	ACRE	1.00	$21.56	$21.56	$21,560.00
FUNGICIDES	ACRE	1.00	$24.56	$24.56	$24,560.00
AERIAL APPLICATION	APPL	1.00	$10.00	$10.00	$10,000.00
IRRIG., MACH & LABOR	IN	4.00	$8.00	$32.00	$32,000.00
HAULING	BU.	68.00	$0.35	$23.80	$23,800.00
CHECK OFF FEE	ACRE	1.00	$1.90	$1.90	$1,900.00
CROP INSURANCE	ACRE	1.00	$18.00	$18.00	$18,000.00
TRACTOR/MACHINERY	ACRE	1.00	$39.33	$39.33	$39,330.00
LABOR	HRS	1.40	$11.25	$15.75	$15,750.00
CROP SCOUTING	ACRE	1.00	$9.00	$9.00	$9,000.00
INTEREST ON OP. CAP.	DOL.	$150.28	$0.07	$10.52	$10,520.00
TOTAL VARIABLE COSTS:				$320.08	$320,080.00
3. INCOME ABOVE VARIABLE COSTS:				$60.72	$60,720.00
4. FIXED COSTS					
TRACTOR/MACHINERY	ACRE	1.00	$55.87	$55.87	$55,870.00
IRRIGATION	ACRE	1.00	$125.00	$125.00	$125,000.00
TOTAL FIXED COSTS:				$180.87	$180,870.00
5. OTHER COSTS					
LAND RENT	ACRE	0.00	$60.00	$0.00	$0.00
GENERAL OVERHEAD	DOL.	$320.08	$0.05	$16.00	$16,000.00
TOTAL OTHER COSTS:				$16.00	$16,000.00
6. TOTAL COSTS:				$516.95	$516,950.00
7. NET RETURNS TO RISK AND MANAGEMENT:				-$136.15	-$136,150.00

Table A5: Average Revenue and Variable Cost of each Crop Under the Four Fertilization Practices.

Year	Revenue ($/acre)			---Variable Cost ($/acre)---											
	Option 1,2,3&4			Option 1			Option 2			Option 3			Option 4		
	Corn	Wheat	Soybean	Corn	Wheat	Soybean	Corn	Wheat	Soybean	Corn	Wheat	Soybean	Corn	Wheat	Soybean
0	$0.00	$0.00	$0.00	$675.42	$345.09		$587.88	$282.13		$674.97	$350.37		$674.97	$324.48	
1	$540.00					$321.08			$320.08			$320.08			$320.08
2		$255.00	$380.80	$701.93	$364.79		$583.83	$280.64		$678.54	$357.66		$678.54	$340.70	
3	$424.05					$321.34			$320.34			$320.34			$320.34
4		$226.49	$459.52	$751.35	$401.51		$583.49	$280.53		$700.42	$370.45		$700.42	$369.90	
5	$749.26					$322.45			$321.45			$321.45			$321.45
6		$366.72	$615.64	$920.99	$520.79		$583.57	$280.65		$756.86	$403.63		$756.86	$447.65	
7	$745.86					$323.21			$322.21			$322.21			$322.21
8		$343.97	$800.82	$849.40	$474.55		$583.46	$280.59		$735.15	$391.28		$735.15	$421.47	
9	$1,274.11					$324.18			$323.18			$323.18			$323.18
10		$564.59	$984.80												

Note: Variable cost computed for corn and wheat includes the land rental cost of @ $60.00 per acre

Key	
Option 1	Commercial Fertilizer Only
Option 2	Broiler Litter only
Option 3	2-ton/acre broiler litter on corn and wheat plus supplemental commercial fertilizer
Option 4	2-ton/acre broiler litter on corn only plus supplemental commercial fertilizer

Table A6: Crop and Broiler Production in South Carolina at the County Level.

COUNTIES	CORN	WHEAT	SOYBEANS	BROILER PRODUCED (HEAD COUNT)	LITTER PRODUCED (Tons)
	ACRES PLANTED				
CENTRAL DISTRICT					
Calhoun	8800.00	D	2700.00	5015000.00	6268.75
Clarendon	33000.00	2000.00	27000.00	11446000.00	14307.50
Lee	31000.00	D	25400.00	3184565.00	3980.71
Lexington	4200.00	D	2500.00	32049914.00	40062.39
Orangeburg	35500.00	2500.00	16400.00	20491100.00	25613.88
Richland	8000.00	1800.00	2700.00	1500000.00	1875.00
Sumter	28500.00	3300.00	25800.00	5859111.00	7323.89
Other counties combined	-	4100.00	-		0.00
TOTAL	149000.00	13700.00	102500.00	79545690.00	99432.11
EASTERN					
Chesterfield	6900.00	6500.00	17100.00	6813000.00	8516.25
Darlington	21500.00	D	35200.00	2726000.00	3407.50
Dillon	22000.00	7200.00	33400.00	7843500.00	9804.38
Florence	22000.00	D	46000.00		0.00
Georgetown	1500.00		3900.00		0.00
Horry	16900.00	1600.00	36200.00	1200000.00	1500.00
Marion	8700.00	D	16300.00	D	-
Marlboro	18000.00	5000.00	22100.00	9771000.00	12213.75
Williamsburg	18500.00		-		0.00
Other counties combined	-	3800.00	-		0.00
TOTAL	136000.00	24100.00	210200.00	28353500.00	35441.88
NORTH CENTRAL					
Chester	D				0.00
Kershaw	D		D	D	-
Lancaster	-			1450000.00	1812.50
Other counties combined	5100.00	3000.00	5200.00		0.00
TOTAL	5100.00	3000.00	5200.00	1450000.00	1812.50
NORTH WESTERN					
Anderson	1200.00	2200.00	3300.00	11102073.00	13877.59
Cherokee	390.00		-	D	-
Laurens	-		-	10028346.00	12535.43
Oconee	500.00		D	36281833.00	45352.29
Spartanburg	700.00	1700.00	3800.00		0.00
Other counties combined	1500.00	3000.00	4800.00		0.00
TOTAL	4290.00	6900.00	11900.00	57412252.00	71765.32

Table A5 continued.

SOUTHERN					
Allendale	8500.00	1200.00	7400.00		0.00
Bamberg	6100.00	D	3600.00	1683292.00	2104.12
Barnwell	5300.00	500.00	3100.00	2711000.00	3388.75
Berkeley	-		1500.00		0.00
Charleston	1000.00				0.00
Colleton	4400.00		2400.00	D	-
Dorchester	7200.00		5100.00	4832000.00	6040.00
Hampton	6700.00	700.00	2900.00		0.00
other counties combined	4300.00	3700.00	800.00		0.00
TOTAL	43500.00	6100.00	26800.00	9226292.00	11532.87
WEST CENTRAL					
Aiken	3200.00			20126828.00	25158.54
Edgefield	700.00		1100.00	2525200.00	3156.50
Newberry	-	5100.00	3200.00	10715295.00	13394.12
other counties combined	9600.00	3500.00	1700.00		0.00
Saluda	2000.00			23690670.00	29613.34
TOTAL	15500.00	8600.00	6000.00	57057993.00	71322.49
Grand Total	353390.00	62400.00	362600.00	233045727.00	291307.16