Analysis of the Effects of Physical Sustainability on Profitability for Crop Production in the Southern High Plains of Texas

by

Miranda Blayne Gillum, B.S.

A Thesis

In

Agricultural and Applied Economics

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

Approved

Phillip Johnson
Chair of Committee

Darren Hudson

Ryan Williams

Mark Sheridan
Dean of the Graduate School

December, 2015

ACKNOWLEDGEMENTS

First, I would like to extend my gratitude to my committee members, Drs. Williams and Hudson, for their insight and encouragement during the thesis process. I would also like to thank my committee chairman, Dr. Johnson, for going above and beyond to help me during my time in grad school. The accomplishment of my research efforts would not have been possible without the guidance and support of my thesis committee. I would like to thank all of the faculty members within the Agricultural and Applied Economics department as their dedication, passion, and support has guided me through a successful journey to reach my educational goals, and for that I am forever grateful. I would also like to thank Jeff Pate for his help with the TAWC data.

Finally, I would like to thank my family. My parents, Randy and Meredith Gillum, and my brother, Adam Emmert, have always pushed me to pursue my dreams and to work diligently to achieve them. They have molded me into the person I am today and were major influences in my pursuance of a Master's degree. DJ Vahlenkamp has always inspired and reassured me throughout my educational career, especially during trying times. Without the patience, encouragement, and support provided by my family, I would not be the person I am today. I can never thank them enough for all the time, faith, and love they have invested in me throughout my life.

I would not be as successful and motivated as I am today without the influence of all these people, as well friends and family not mentioned. I would like to thank everyone for their encouragement and support.

TABLE OF CONTENTS

ABSTRACT

Agricultural sustainability encompasses both physical sustainability as well as economic sustainability. The relationship between physical sustainability and profitability is often assumed to be negative; however, little actually is known about the relationship between practices that enhance physical sustainability and economic sustainability. The focus of the study was to analyze the impact of physical sustainably on economic sustainability for producers in the Southern High Plains of Texas.

A regression analysis using Ordinary Least Squares (OLS) was conducted to estimate two effects: the impact of sustainability metrics on profitability expressed as gross margin, and the impact of irrigation and tillage systems on sustainability metrics. This analysis allows producers in the Southern High Plains region to better understand the implication of particular production practices on sustainability metrics as well as the effects of sustainability metrics on profit. Results from the study indicate that improving land use, irrigation water use, and energy use metrics may maintain or improve profit for cotton and corn operations in the Southern High Plains region. In addition, furrow (FUR) irrigation systems have a negative effect on the land use, irrigation water use, and energy use metrics. MESA systems have negative effect on the land use and soil conservation metrics. SDI and no-till (NT) systems have a positive effect on soil conservation when compared to the bases LESA and conventional tillage, respectively. Results from the study conclude that profitability does not appear to be negatively affected by sustainability and certain irrigation and tillage systems affect sustainability metrics when compared to the base systems.

LIST OF TABLES

LIST OF FIGURES

CHAPTER I
INTRODUCTION

General Problem Description

Sustainability in agriculture has become an important issue for many involved in agricultural production, marketing, processing, and retailing. Many companies are beginning to focus on sustainability goals and targets as well as encourage producers to adopt more sustainable practices. In addition, some companies are taking steps to reduce the environmental impact of their products and services in response to consumer preferences (Perera et al., 2013). Defining sustainable agriculture can be a difficult task. According to Sustainable Agriculture Research & Education (SARE), there are three pillars of sustainability in agriculture: profit over the long term; stewardship of the land, water, and air; and quality of life for farmers, ranchers, and their communities. If these three pillars are fulfilled, a production operation is considered sustainable. Sustainability is important as it effects everyone, not just those who are directly involved in agriculture. The world population is growing rapidly and our resources are limited, therefore it is important for producers to increase their productivity which can possibly be accomplished by improving agricultural sustainability. By becoming more sustainable, a producer can reduce their carbon footprint and potentially reduce the harmful effects of agriculture on the environment while fulfilling the food and fiber needs of the world.

Sustainable agriculture produces food and fiber without depleting natural resources while developing systems for raising crops and livestock that are self-sustaining (Earles and Williams, 2005). According to Earles and Williams (2005), there are several key considerations for making a farm more sustainable: know your markets, protect your profits and add value to your products, build soil structure and fertility, protect water quality on and beyond the farm, manage pests ecologically and use minimal pesticides, and maximize biodiversity on the farm. In farming, it is important to keep accurate records of all activity that occurs on an operation such as chemical, fertilizer, and irrigation applications; tillage timing and practices; and rainfall data. By maintaining accurate records, a producer can better determine which factors influence their operations at given times and can adjust their management practices to achieve more optimal results.

There are different types of sustainability such as environmental sustainability and economic sustainability. Environmental sustainability focuses on restoring and repairing damages placed on natural resources whereas economic sustainability pertains to producers maintaining profit over a long period of time that allows them to be economically viable. A good business will focus on both forms of sustainability in order to balance the right business strategies. Yet, reaching an efficient balance between the two is difficult since business strategies and environmental strategies may not line up (Perera et al., 2013). As consumer preferences grow for sustainable agricultural products and natural resources are depleted, there is great incentive for producers to adopt more sustainable practices in their production operations. Though it is often perceived that environmental and economic sustainability efforts are not related, an agricultural operation must be profitable to be considered sustainable according to SARE. Therefore, any mention of sustainability henceforth refers to physical sustainability that will be compared to economic sustainability.

A major issue regarding sustainability in agriculture concerns the use of irrigation water. Irrigated agriculture that depends on nonrenewable water sources is not sustainable at its present state. However, if producers can adopt improved water management practices as well as more efficient irrigation application systems, the agricultural community can more readily adapt to water-supply deficits and enhance long run sustainability (USDA). Yet, the willingness and ability of producers to adopt more efficient irrigation practices could be a major factor in improving irrigated agriculture. With growing demand for water resources, sustainability of irrigated agriculture is possibly more important than ever. According to the USDA, the future sustainability of irrigated agriculture will depend on water-use efficiency; conservation policies that encourage more efficient on-farm water management; and how and when scarce water supplies are reallocated among competing demands (48). Many individuals now realize that though water is currently available, rapid extraction rates could cause depletion in the future. Consequently, sustainable agriculture is a growing concept and many in the agriculture sector as well as consumers are focusing their efforts towards sustainability.

In the Southern High Plains of Texas (SHP), rain is a vital resource given that average annual rainfall is about 18 inches (NOAA, Lubbock precipitation). Therefore, many producers rely on irrigation to produce more desirable yields than they would get solely from rain fed production. Most of the irrigation water used for crops in the SHP is drawn from the Ogallala Aquifer. The Ogallala Aquifer underlies approximately 225,000 square miles in the Great Plains region. The aquifer lies beneath the majority of the SHP as well as parts of Oklahoma, New Mexico, Colorado, Wyoming, South Dakota, and the majority of Kansas and Nebraska, as seen in Figure 1.1.

Figure 1.1. Map of the Ogallala Aquifer.

The aquifer is one of the largest underground freshwater sources in the world and has been a major resource in agricultural production in the Great Plains. Due to the reliance on the Ogallala Aquifer in the Texas Southern High Plains region, the withdrawal rate has been much greater than the recharge rate. Consequently, the current withdrawal from the southern portion of the Ogallala Aquifer is too high to be considered sustainable and the aquifer is at risk of depletion if conservation efforts are not taken (MIT). Approximately 95% of the water pumped from the aquifer is used for agriculture. Water levels in the aquifer have declined consistently through time, however in recent years, the rate of decline has slowed and water levels have risen in some areas (Texas Water Development Board, 2015).

Specific Problem Description

The Texas Alliance for Water Conservation (TAWC) project collects information from cropping and livestock systems to compare production practices, technologies, and irrigation systems. The demonstration farms within the project represent a wide variety of agriculture practices including monoculture cropping systems, cropping rotations, integrated livestock and crop systems, no-till, minimum-till, and conventional tillage practices. There are also different irrigation management systems including dryland, subsurface drip irrigation, center pivot irrigation (LESA, LEPA, MESA), and furrow irrigation. These demonstration farms are primarily located in Hale and Floyd counties in the SHP. Other counties include Castro, Crosby, Deaf Smith, Lamb, Lubbock, Parmer, and Swisher. Figure 1.2 shows the counties that are in the TAWC demonstration project.

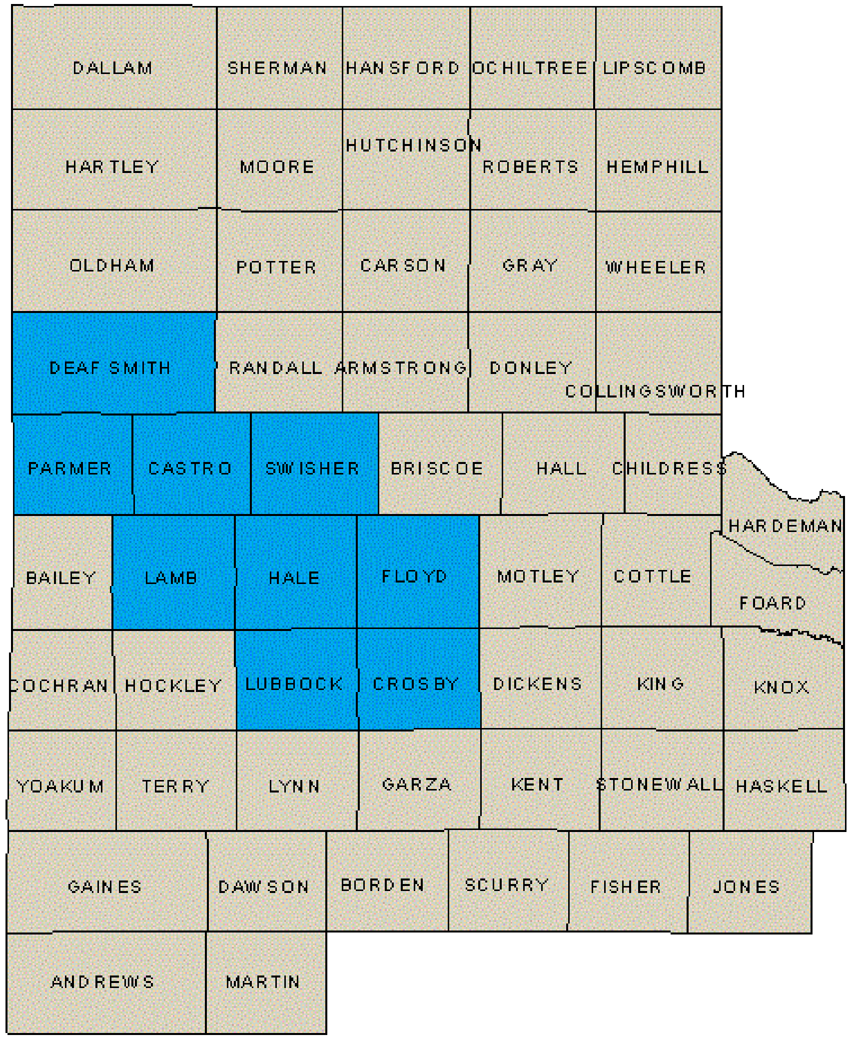

Figure 1.2. Map of the Southern High Plains of Texas.
***Blue counties indicate locations of demonstration farms in the TAWC project.**

The project has collected data from approximately 30 producers from the years 2007 through 2014. During this time producers planted roughly 13,768 acres of cotton, 5,039 acres of corn (grain), 2,998 acres of grain sorghum, 259 acres of alfalfa, 2,468 acres of wheat, 3,226 acres of sideoats grama, 831 acres of millet, 1,120 acres of triticale, 1,455 acres of sunflowers, and 1,956 acres of corn (silage). The project sites were monitored and data was collected for irrigation water, crop water demand, yields, input costs, and overall producer profitability. The major differences in demonstration farms are likely due to varying farm management practices. Due to this, the sustainability of each operation can be evaluated based on management practices with little to no influence from outside factors. The sustainability of the TAWC demonstration farms will be analyzed using the Fieldprint® Calculator.

The Fieldprint® Calculator is an analytical tool that evaluates crop production operations and computes metrics to measure their sustainability and operational efficiency. The calculator allows agricultural producers to measure the sustainability of their operations, and researchers to analyze the effects of different production practices on sustainability and the environment (Field to Market®, 2015). The calculator was developed by Field to Market® – the Keystone Alliance for Sustainable Agriculture – and is a free, online resource. Field to Market® is a collaboration of producers, agribusinesses, conservation organizations, universities, and public sector partners who are working towards continuous improvements in productivity, environmental quality, and human well-being. Their efforts focus on measuring and advancing the sustainability of food, fiber, and fuel production in the agricultural supply chain. Field to Market® has several on-going projects located in Iowa, Louisiana, Michigan, Oklahoma, and Texas as well as projects with Unilever and ADM. The Texas Cotton project, which uses the data from TAWC demonstration farms, is sponsored by the National Cotton Council and Natural Resources Conservation Service.

In the calculator, a producer will spatially locate their field then input their operational information such as crop rotation, management systems, transportation, drying, and crop input amounts and timing. There are seven metrics in the calculator that measure the sustainability of an operation: land use (ac/unit of production), irrigation water use (in/unit of production), energy use (gallons of diesel/ unit of production), greenhouse gas emissions (lbs CO_2/ unit of production), soil conservation (tons of soil loss/ac/yr), a soil carbon index, and a water quality index. The calculator generates these metrics and provides a graphic sustainability footprint in the form of a spidergram (Figure 1.3). By assessing these metrics, the calculator enables a producer to explore different management practices in order to improve the sustainability of their farming operation. Additionally, the calculator allows each farmer to compare their current farming practices (shaded purple area) to the county, state (orange), and national (green) averages. The national average is calculated using a five-year Olympic moving average. A producer enters data into the calculator each year, allowing them to compare multiple sites across many years. The calculator allows producers to visualize and assess how various management decisions effect operational efficiency and their environmental impacts.

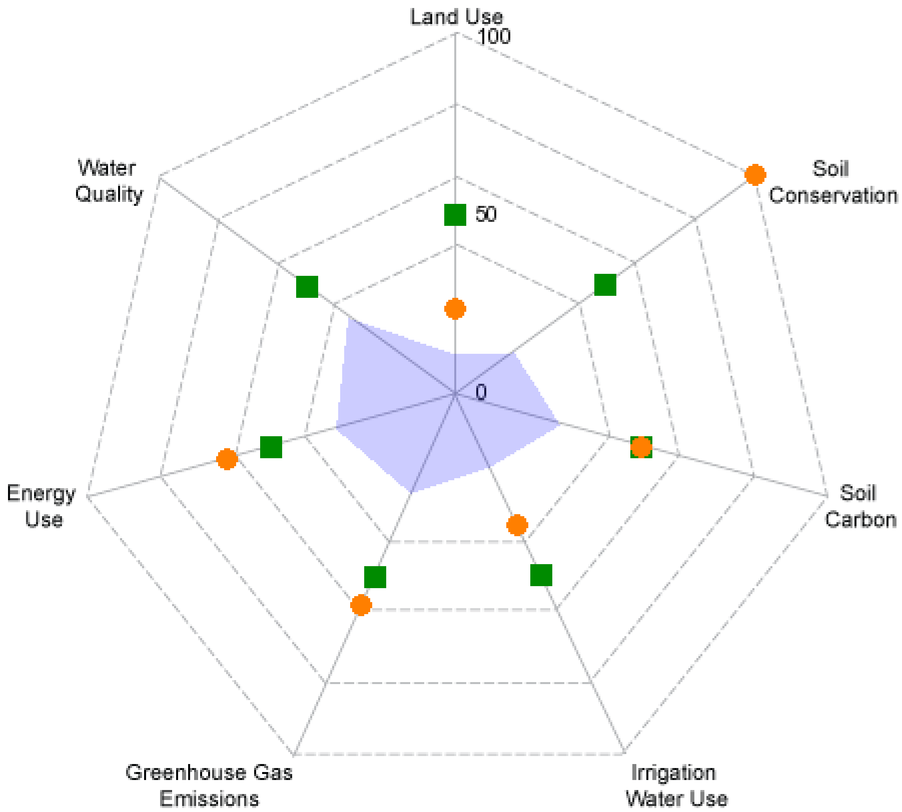

Figure 1.3. Spidergram representing the seven metrics in the Fieldprint® Calculator.

Since irrigated agriculture is the dominant method for crop production in the SHP, analyzing sustainable irrigation strategies is important for the continued viability of the operations in this region. Though irrigation is an important factor in agricultural sustainability, tillage and soil management strategies are also vital for maintaining the region's natural resources. By maintaining the soil used for producing crops, a producer could potentially see positive long term effects on their operations. Therefore, it is imperative that all aspects of sustainable agriculture are analyzed when evaluating production operations.

According to SARE, an operation must be able to maintain long-term profitability in order to be considered sustainable; however, the Fieldprint® Calculator does not consider profit when calculating sustainability metrics. In the calculator, there is no index that explicitly analyzes profit. Assuming the number one goal of the producer is profit maximization, it is important that a relationship between the sustainability metrics and profit be considered. This study will analyze the relationship between profitability and sustainability in order to evaluate the correlation between the two. This will be beneficial to producers as they can see how changing management practices not only influences their sustainability metrics, but also may affect the profitability of their operation.

Objectives

The primary objective of this study is to evaluate production practices for producers in the SHP with respect to sustainability and profitability. The specific objectives are:

1. To estimate the effects of agricultural sustainability on profit for operations in the Southern High Plains of Texas.
2. To compare irrigation and tillage systems to evaluate the sustainability of different production practices in the Southern High Plains of Texas.

CHAPTER II
LITERATURE REVIEW

The concept of sustainable agriculture has been around for many decades, yet many in the agricultural sector are recently realizing the importance of sustainability efforts. Many involved in agricultural retail, marketing, and production are pursuing efforts to improve agricultural sustainability. Improving agricultural sustainability is beneficial to producers and consumers alike and is imperative for future generations to prosper in their agricultural endeavors. Producers can likely see positive long term effects on their operations by adopting more sustainable agricultural practices. This chapter will cover various aspects related to sustainable agriculture in the SHP such as 1) the Ogallala Aquifer and irrigation, 2) environmental and economic sustainability, and 3) the Fieldprint® Calculator.

The Ogallala Aquifer and Irrigation

Schaible and Aillery (2012) discussed the trends and challenges for the sustainability of irrigated agriculture in the United States. They state that managing `irrigation applications, such as the timing and amount of water based on the requirements of the crop, is a necessary step for the sustainability of irrigated agriculture. They also state that climate change and increased demand for water has a major impact on irrigation which will further constrain water resources. Climate change will result in higher evaporation rates due to rising temperatures, making water application from high-pressure sprinkler and traditional gravity irrigation systems less efficient (Schaible and Aillery, 2012). Therefore, the adaptability of irrigated agriculture could result in an increased use of efficient gravity and pressurized irrigation systems as well as the implementation of intensive water management practices. They state that by coupling water management practices with efficient irrigation systems, a producer can improve the long run sustainability of their operation. They reveal that irrigated agriculture accounted for 40% of market sales in 2007 and the average value of farm products from irrigated farms was 3.3 times the average value of dryland farm products. In 2007, 56.6 million farmland acres were irrigated in the United States with 8.9% of the acres being in Texas. They found that 10 of the 12 leading irrigation states were all in the Western United States and accounted for 77.3% of irrigated acres. Of the Western United States, the Southern Plains accounted for 12% of the total irrigated acres. They state that cost differences impact irrigation profitability which can fluctuate based on available water sources, type of irrigation system used, type of crops, energy source used to power irrigation pumps, and water costs charged for off-farm water supplies.

Guerrero and Amosson (2013) analyzed the importance of irrigated crop production to the Texas High Plains (THP) economy. In the study, they determined that agriculture is a major economic driver for the region. In the THP, approximately 90% of water usage from the Ogallala Aquifer is used for agriculture, making the aquifer the primary source of water for irrigated agricultural production. Due to this, there are many concerns about the appropriate allocation of water to agricultural, industrial, and municipal uses. Consequently, valuing agricultural irrigation will allow policymakers to develop appropriate water management strategies that have minimal impacts on the regional economy (Guerrero and Amosson, 2013).

Guerrero and Amosson (2013) used an input-output model using two different scenarios, one where producers operate in an unregulated manner and another that assumed all irrigated acreage is converted to dryland. These scenarios were used to estimate the economic contribution of irrigated agriculture and determine a monetary value for irrigation water. The results indicated that irrigated agriculture contributes roughly $6.6 billion in industry output, $2.1 billion in value added, and supports 58,900 jobs in the THP. When the irrigated acreage was converted to dryland, the land would contribute $2.2 billion in industry output, $717 million in value added, and support 34,600 jobs in the THP. They then estimated the regional economic value per acre-inch of water applied. Given that the difference in industry output between the irrigated and dryland scenarios is $4.3 billion and approximately 54 million acre-inches were applied to crops, the value of irrigation water is around $80 per acre-inch of water applied. From the results, they determined that the water from the Ogallala Aquifer is a vital resource for irrigated agriculture in the THP. Therefore, if policymakers reduced the amount of water used by agricultural producers, the region would suffer serious negative consequences.

Peterson and Ding (2005) analyzed various irrigation systems to determine if more efficient systems save water. The study was conducted in the High Plains region focusing on the depletion of the Ogallala Aquifer. The study revealed that when compared to furrow irrigation systems, sprinkler systems and subsurface drip systems deliver 17% and 27% more water to the crop root zone, respectively. Additionally, total seasonal irrigation was reduced by using sprinkler and subsurface drip systems when compared to the furrow system. They determined that improved irrigation efficiency led to increased yields, even if total seasonal irrigation declined. In the study, subsurface drip systems were the optimal choice, yet the higher cost of the system could make it less attractive to producers unless a government cost share program was enacted, which could be an effective strategy for conserving groundwater (Peterson and Ding, 2005).

Amosson et al. (2006) identified and evaluated water management strategies that, if implemented, could potentially reduce the amount of irrigation water used in the Texas High Plains. The conservation strategies included: the use of evapotranspiration (ET) data for irrigation scheduling; changes in crop varieties; irrigation equipment improvements; changes in crop type; implementation of conservation tillage methods; precipitation enhancement (a process in which seeding agents are used to stimulate clouds to produce more rainfall); and converting irrigated acreage to dryland. The seven strategies were initially identified by the Region A Agricultural Demands and Projections Committee in the Senate Bill 1 planning effort to conserve water in the Northern Texas High Plains (Region A). In response to the Senate Bill 2, Amosson et al. (2006) identified the cost and regional impacts of implementing the seven water management strategies. They determined that all strategies conserved water, but some had negative impacts on the region's economy. Table 2.1 shows the cumulative water savings, implementation cost, and direct regional impacts which are expressed by the change in gross crop receipts for each of the seven water management strategies (Amosson et al., 2006).

Table 2.1. Estimated Water Savings and Costs Associated with Proposed Water Conservation Strategies in Region A.

Water Management Strategy	Cumulative Water Savings (WS) ac-ft	WS/Total Irrigation Demand %	Implementation Cost (IC) $1,000	IC/WS $/ac-ft	Direct Regional Impact (DRI)[1] $1,000	DRI/WS $/ac-ft
Use of Irrigation Scheduling	2,065,469	1.96	8,100	$3.92	+	+
Change in Crop Variety	6,658,309	6.32	-	-	-1,548,584	-$232.58
Irrigation Equipment Changes	4,124,398	3.91	169,608	$41.12	-	-
Change in Crop Type	8,709,995	8.26	46,000	$5.25	-2,054,000	-$235.85
Conservation Tillage Methods	2,135,882	2.03	10,985	$5.14	-	-
Precipitation Enhancement	4,105,680	3.89	25,800	$6.28	+	+
Irrigated to Dryland Farming	5,157,272	4.89	39,000	$7.54	-406,000	-$78.72

+ indicates an anticipated positive impact that was not quantified.
- indicates an anticipated neutral impact on the regional economy.

As seen in Table 2.1, changing the crop type and crop variety, as well as converting irrigated acreage to dryland resulted in the greatest amount of water savings, but had great negative impacts on the economy of the region. Amosson et al. (2006) determined that precipitation enhancement and the use of irrigation scheduling would have a positive impact on the region's economy while irrigation equipment changes and conservation tillage methods would have a neutral effect.

Environmental and Economic Sustainability

Weinheimer et al. (2010) compared the net carbon relationships, economic viability, and irrigation efficiency of irrigated cotton and corn production systems in the SHP of Texas using data from the TAWC project. They suggest that sustaining the region's economic base and production capabilities could be a challenge if a potential cap and trade system for carbon emissions is implemented. They chose to evaluate four irrigated cotton sites and two irrigated corn sites from the 2008 growing season. The corn sites had center pivot irrigation while the cotton sites had center pivot, subsurface drip, and furrow irrigation systems. Weinheimer et al. (2010) split field level inputs into categories: fuel, fertilizer, chemicals, and electricity which each had an average carbon equivalent that was previously documented. These values were applied to the total amount of each input used for a specific field, which resulted in the total amount of carbon emitted from the use or consumption of an input. Irrigation carbon emissions and the biological component of carbon were also evaluated.

Weinheimer et al. (2010) determined that the corn sites produced an average net carbon balance of 7,476 lbs/acre while the cotton sites produced 4,201 lbs/acre. Moreover, the corn sites had an average gross margin and average irrigation efficiency of $703/acre and $59/acre inch of water, respectively. In addition, the cotton sites had an average gross margin and average irrigation efficiency of $257/acre and $19/acre inch of water, respectively. They point out that the corn price in 2008 was at higher levels than the average marketing year, so the profit levels should not be considered a long run average. The higher levels of carbon in the soil for corn was expected given that corn produces more biomass than cotton (Weinheimer et al., 2010). Though the corn sites had higher levels of input carbon due to intensive input usage, such as irrigation and fertilizer, the corn sites on average had a 78% higher carbon balance when compared to the cotton sites. They conclude that corn has several advantages over cotton by its ability to return carbon to the soil (which reduces atmospheric CO_2), maintain profitability, and use water resources efficiently. The study provides producers and policy makers with important information regarding the carbon balance and economic viability of two major crops in the SHP. Overall, producers who can move between irrigated corn and cotton should evaluate the advantages of corn.

Gramig and Widmar (2014) estimated farmers' willingness to change tillage practices in order to supply carbon emissions offsets. A random sample of 2,000 farmers who plant corn and soybeans in Indiana was evaluated, with a response rate of 42%. They state "offsets" which include emissions credits or certified emissions reductions (CERs) can be used as a policy component to reduce greenhouse gas emissions (GHG). The offsets allow firms covered by emissions limits or who must pay carbon taxes, to purchase emissions credits by reducing emissions that are not affected by the emissions limits or carbon taxes. In the study, they estimate producers' willingness to change (WTC) their management practices, such as adopting conservation tillage techniques to sequester atmospheric carbon in soil, in order to achieve environmental policy objectives. A choice experiment was conducted to determine producers' preferences for alternative tillage practices and related attributes to incentivize broader adoption of reduced tillage systems.

Gramig and Widmar (2014) determined that farmers' willingness to pay for implementation of conservation and conventional tillage was $3.21 and $4.79, respectively, and are interpreted as the dollars per acre a producer is willing to pay to implement the tillage practices relative to no-till. They also discovered that farmers would require payments of $10.57 per acre to accept a multi-year contract that limits their ability to change tillage practices during the contract term. The results indicated that farmers would rather receive no payments than be paid by either source evaluated in the study (Gramig and Widmar, 2014). These results are consistent with the expectation since the study included alternatives with no carbon payment from either source, but a potential increase in net revenue by adopting either conservation tillage or no-till (Gramig and Widmar, 2014).

Osteen et al. (2012) discuss the importance of soil management and soil conservation, particularly focusing on tillage practices. They mention that farm management strategies such as crop residue management, crop rotations, and soil conservation can improve or maintain soil quality, mitigate environmental damage, and increase economic returns. Tillage and crop residue management have become important issues for producers and policymakers due to rising fuel prices, concerns about air quality issues, acreage increases of crop mixes with higher moisture requirements, and carbon sequestration potential of agricultural soils. They acknowledge the role conservation tillage plays in crop residue management and the effects it has on the environment and the economy such as: reduced fuel and labor expenditures; improved water holding capacity of the soil; decreased soil water evaporation; improved water infiltration;

reduced soil erosion; and reduced water pollution. They also discuss the importance of crop rotations for soil nutrient management as well as the disruption of weeds, insects, and disease which reduces pesticide application and costs. Crop rotations also increase vegetative cover and can reduce soil erosion, reducing nutrient and pesticide runoff into waterways. They mention several conservation structures which help minimize erosion and sedimentation runoff such as terraces; grassed waterways; grade stabilization structures; filter strips; and riparian buffers.

O'Connor (2014) recommended that the Federal Crop Insurance Program (FCIP) should incentivize farmers to implement farm management practices that improve soil quality as they potentially reduce the risk of crop loss due to weather related consequences. She states that the FCIP should lower premiums for producers who implement certain management practices since improving soil health aids in counteracting environmental consequences, making it a risk management strategy. According to O'Connor (2014), the FCIP premium rates attract high-risk producers and the structure of the program incentivizes production choices that damage natural resources, increasing the risk of crop loss. She states that no-till farming, cover cropping, and efficient irrigation are three soil-building practices that decrease the risk of crop loss, mainly by increasing the water holding capacity of the soil. No-till management increases soil moisture, reduces soil erosion, and increases biodiversity in the soil. Cover crops also increase water infiltration and storage, reduce soil erosion, and increase biodiversity as well as suppress weeds, increase soil fertility, and reduce input requirements. Adoption of cover crop technologies has been slow and is likely due to farmers' unfamiliarity with cover crops, as well as the increased time and labor required. By scheduling irrigation according to data from soil moisture monitors and evapotranspiration data, farmers can improve yields while using less water which reduces short-term costs and conserves water. She concludes that the FCIP should use a pilot program which lowers insurance premiums for farmers who use on-farm stewardship to reduce the risk of crop loss.

Allen et al. (2005) compared a cotton monoculture system and an integrated cotton/forage/livestock system to determine if either system reduced water withdrawals from the Ogallala Aquifer. The study included both systems which were located in Lubbock County, Texas. The monoculture system used conventional tillage while the integrated system used no-till, both systems utilized subsurface drip irrigation. They determined that the integrated system used less irrigation water when compared to the monoculture system, which was likely due to the water-use efficiency of the perennial grass in the integrated system. Approximately 40% less nitrogen fertilizer was applied to the integrated system when compared to the monoculture system, reducing costs and energy inputs.

Allen et al. (2012) continued the research of Allen et al. (2005) and determined that the lower water use in the integrated system occurred due to the reduced cotton acreage. Nitrogen fertilizer was still lower in the integrated system than in the monoculture cotton system, and grazing in the integrated system did not reduce weed presence when compared to the monoculture system. It was suggested that greater integration of crops and livestock could improve production quality and quantity as well as reduce pressure on soil and water resources. Crop rotations in the integrated system provide many benefits such as reduced soil erosion; greater soil microbial biomass and enzyme activities; increased soil organic carbon and soil aggregate stability; significant changes in bacterial phyla distribution; greater potential for carbon sequestration; greater protection against soil-borne diseases; and diversification of income sources (Allen et al., 2012).

Mitchell et al. (2013) analyzed the profitability of the integrated cotton/forage/livestock production system and the cotton monoculture system in the SHP using a simulation approach. They compared productivity, water and energy use, and economic returns for both systems in Lubbock County, TX from 1999 to 2008. The results indicated that the integrated system had an average revenue of $1,090 per acre while the monoculture system had an average return of $767 per acre. In addition, the cotton monoculture system and the integrated system had a 13% and 58% chance of receiving revenue greater than $1,000, respectively. The monoculture system had a 41% chance of receiving revenue less than $700 while the integrated system had a 7% chance. The simulated cash expenses for the monoculture system and the integrated system average $657 per acre and $986 per acre, respectively. Moreover, the chances of expenses being less than $650 in the monoculture and integrated system were 47% and 7%, respectively, while the probability of expenses being greater than $850 was 13% for the monoculture system and 76% for the integrated system. The average gross margin for the monoculture system was $108 per acre and $104 per acre for the integrated system. The monoculture system has a 14% chance of receiving negative gross margins and a 37% chance of gross margins exceeding $150 per acre. The integrated system has a 29%

chance of receiving negative gross margins and a 45% chance of gross margins exceeding $150 per system acre. Figure 2.1 shows the probability of each system receiving negative gross margins and gross margins greater than $150 per acre. Mitchell et al. (2013) determined that the cotton monoculture system was the most preferred by stochastic rankings that were conducted, and was the most profitable based on gross margin. Though the cotton monoculture system proves to be more profitable in the SHP than the integrated cotton/forage/livestock system, Table 2.2 shows that overall, the integrated system has a higher gross margin per acre inch of water applied, making it a viable option in the future for conserving water resources.

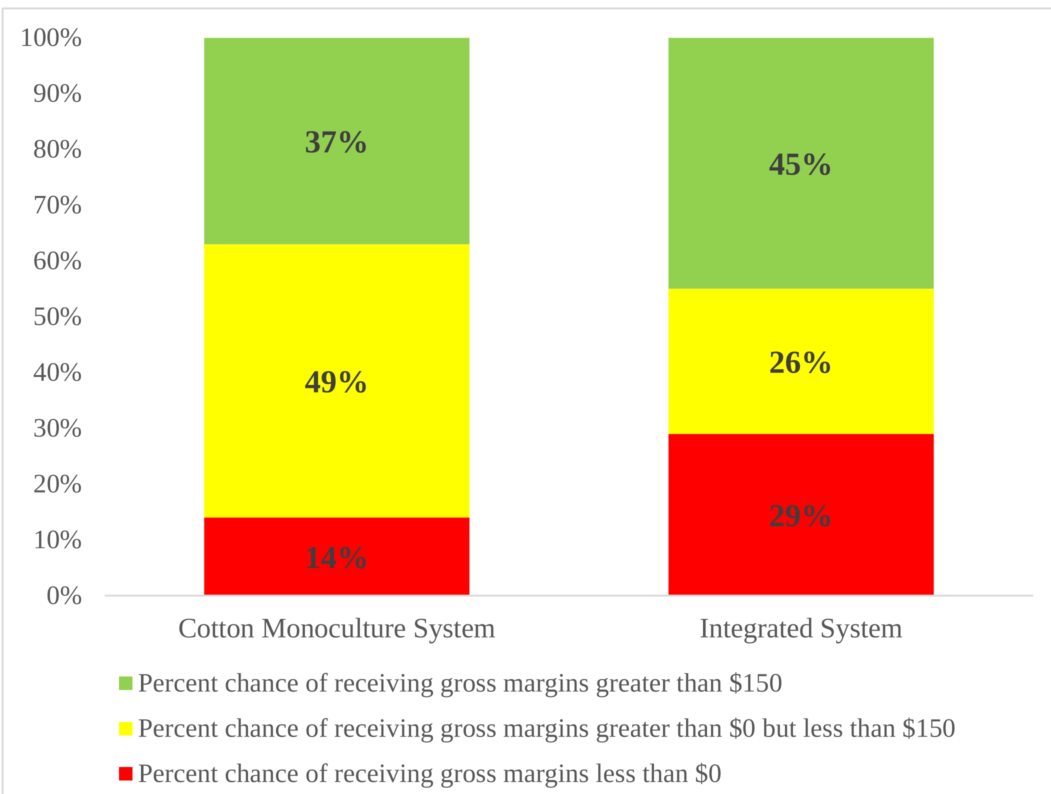

Figure 2.1. Stoplight/Probability chart for gross margin under the cotton monoculture and integrated systems.

Table 2.2. Gross Margin per Acre Inch of Water for the Cotton Monoculture and Integrated Systems.

Gross Margin per Acre Inch of Water		
Year	**Cotton Monoculture**	**Integrated**
1999	0.69	12.20
2000	-2.79	-1.08
2001	0.77	4.69
2002	0.38	1.72
2003	21.03	19.85
2004	19.25	32.89
2005	4.71	-2.06
2006	3.80	-7.23
2007	13.87	32.71
2008	27.51	30.46
Average	8.92	12.41

Johnson et al. (2013) determined the economic viability of integrating cotton and beef production for systems located in northeast Lubbock County, Texas from 1999 to 2008. When evaluating the actual price scenario, the integrated system was more profitable for the first four years (1999-2002) by approximately $155. The introduction of higher yielding cotton cultivars increased yields in both systems during the last six years (2003-2008) of production, yet the cotton monoculture system proved more profitable during the time period. However, the integrated system used 24% less applied irrigation, which could be a viable option for producers located in areas where irrigation is limited; had less economic risk due to the variation of profitability; and benefitted soil health and wildlife populations by adding ecological diversity. Overall, the monoculture system proved to be more profitable, but the integrated system reduced economic risk and provided many non-market benefits which reduce the effects on the environment, improves soil quality, and improves wildlife habitat. They suggest that producers consider the management requirements of an integrated system before transitioning from a monoculture production system.

Fieldprint® Calculator

Hamilton and Reaves (2014) evaluate efforts being made by collaborating food and beverage companies to assess and improve sustainability for the agricultural supply chain as well as production operations in the United States. They discuss the importance of agricultural sustainability in all sectors as well as aligning sustainability goals and metrics between the companies involved. They discuss conservation steps which have made farmers more profitable over time including: better management of inputs and water, and land management strategies that improve soil health. In fact, once farmers realized the importance of improving their operational sustainability, they began implementing other conservation practices that did not affect profit but improved the local habitat. They also discuss the importance of advisors for farmers as they provide farmers with guidance for improved sustainability. One group, Field to Market®, has developed the Fieldprint® Calculator to measure a producer's sustainability which allows the producer to see the effects of particular farm management practices. They mention that as farmers analyzed results from the calculator, they compared their management practices to other local farmers and began devising ways to reduce their impact on the environment.

The Fieldprint® Calculator is used in the Paw Paw region in Michigan to engage and educate farmers about sustainability in addition to informing the conservation district of the farmer's practices and philosophy. Hamilton and Reaves (2014) highlight that the

Fieldprint® Calculator has had a positive impact on many growers in the pilot programs as it has encouraged them to make field specific improvements in order to improve their sustainability. In fact, producers in the Paw Paw River Watershed pilot and the Boone River Water shed in Iowa receive compensation from the Coca-Cola foundation when they enter field data into the calculator, as well as when they improve management strategies that lead to groundwater recharge such as no-till, reduced-till, cover crops, and other beneficial practices. They mention the importance of the Boone River Watershed pilot in the Fieldprint® Calculator as the impacts realized from the tool informs companies such as Cargill, Walmart, and others how to improve the environmental impacts of the corn that is used through their systems.

Duncan et al. (2015) analyzed the influence of management practices on cotton sustainability in Tennessee by using the Fieldprint® Calculator tool. The study analyzed 83 fields with a total of around 5,800 acres in 12 of the major cotton growing counties in Tennessee. The study compared management strategies in the following areas: tillage systems, cover crops, irrigation, and precision nutrient management. They analyzed several fields under no-till and conventional tillage management practices, discovering that energy use and soil loss was always reduced for the no-till scenario. However, slope, slope length, soil type, and other factors can result in higher erosion for certain fields. One particular field reduced its soil loss by about 3 tons/ac/year for a total savings of 142 tons of soil in 2013. Water quality also improved due to the reduction of soil loss.

Duncan et al. (2015) discovered that the use of cover crops reduced the amount of energy used on several fields as well as the greenhouse gas emissions. This was due to lower amounts of synthetic nitrogen fertilizer used. One field in the study improved energy usage by 2575 BTU/lb lint and reduced greenhouse gas emissions by approximately 0.3 CO_2/lb lint. The importance of cover crops is increasing as some integrate nitrogen back into the soil and can suppress early season weeds, reducing input costs and improving sustainability (Duncan et al., 2015). They determined that irrigation management practices such as proper timing and application of water is important for reducing energy use and greenhouse gas emissions. They also concluded that proper irrigation management used to optimize yields can be more sustainable than dryland cotton. They analyzed the use of variable rate application (VRA) for fertilizer and determined that overall, producers used less fertilizer using VRA than uniform fertilization. By using VRA, the producer saved around $81/ac/year in fertilizer costs which reduced greenhouse gas emissions by 1.4 million lbs CO_2; energy use by 18 billion BTU; applied Nitrogen by 28.7 tons; applied P_2O_5 (Phosphorus Pentoxide) by 36.9 tons; and input costs by over $127,000. Duncan et al. (2015) concluded that using the Fieldprint® Calculator is beneficial to producers as it quantifies the sustainability of production operations and allows them to visualize the effects of improving farm management strategies.

CHAPTER III
CONCEPTUAL FRAMEWORK

For a producer in the SHP of Texas, there are many factors that should be considered in the transition to sustainable agriculture. A producer must weigh the costs and benefits of each sustainable practice in order to adopt the most appropriate systems for their operation. First, it is assumed that a producer is a profit maximizer. Therefore, any practice implemented by the producer must generate equal or greater profits than their previous production practices. However, the transition to new production practices may act as a long term investment where the producer may not experience adequate profit in the short run. This chapter will analyze economic theory related to resources used by producers in the SHP of Texas as well as their production operations.

Cobb-Douglas Production Function and Technological Change

Cobb and Douglas (1928) developed a theory of production which suggested that there was a relationship present between the amounts of inputs, particularly capital and labor, and the amount of output produced by the inputs. The model they developed appears as follows:

$$P(L, K) = bL^{\alpha}K^{\beta}$$

Where:

P = total production
L = labor input
K = capital input
b = total factor productivity
α = output elasticity of labor (constant determined by available technology)
β = output elasticity of capital (constant determined by available technology)

For this study, we are focusing on b (total factor productivity) from the Cobb-Douglas equation above. One way for a producer to experience an increase in profit is to implement technological change. Technological change will allow a producer to see increases in yield which in turn increases profit. In agriculture, producers use applied scientific knowledge to improve their production process, known as technological change (Carlson et al., 1993). Technology is an important factor for producers as it has a large impact on the productivity of a given operation. According to Carlson et al. (1993), technological change can be realized in several different ways: changes in input quality, knowledge of improved methods of production, and the invention of new processes and inputs. Some examples of the different types of technological change are: inputs (pesticides, fertilizers, etc.) and input management, tillage and irrigation techniques and/or systems, planted crop varieties, and farm management strategies. One or a combination of these factors can greatly improve the productivity of an operation, yet the amount of improvement is dependent upon previous technological use.

An example of technological change that has impacted crop production in the SHP is the adoption of crop varieties that have higher yield potential and traits such as herbicide and insect resistance. Producers have experienced increased crop yields and higher profits using new crop varieties when compared to conventional varieties. These improved varieties carry traits which are superior to their predecessors, allowing them to produce higher yields. They also provide many benefits such as: better crop yields; better resistance to weeds, pests, and diseases; require less use of pesticides; create food with better texture, flavor, and nutritional value; create foods with a longer shelf life; and they can potentially reduce soil erosion by conserving soil moisture and reducing the amount of tillage. The effects of old and new varieties on yield are seen below in Figure 3.1. The use of new crop varieties causes an upward shift in the production function, meaning that by using the same levels of inputs, a producer can experience greater output with the new varieties.

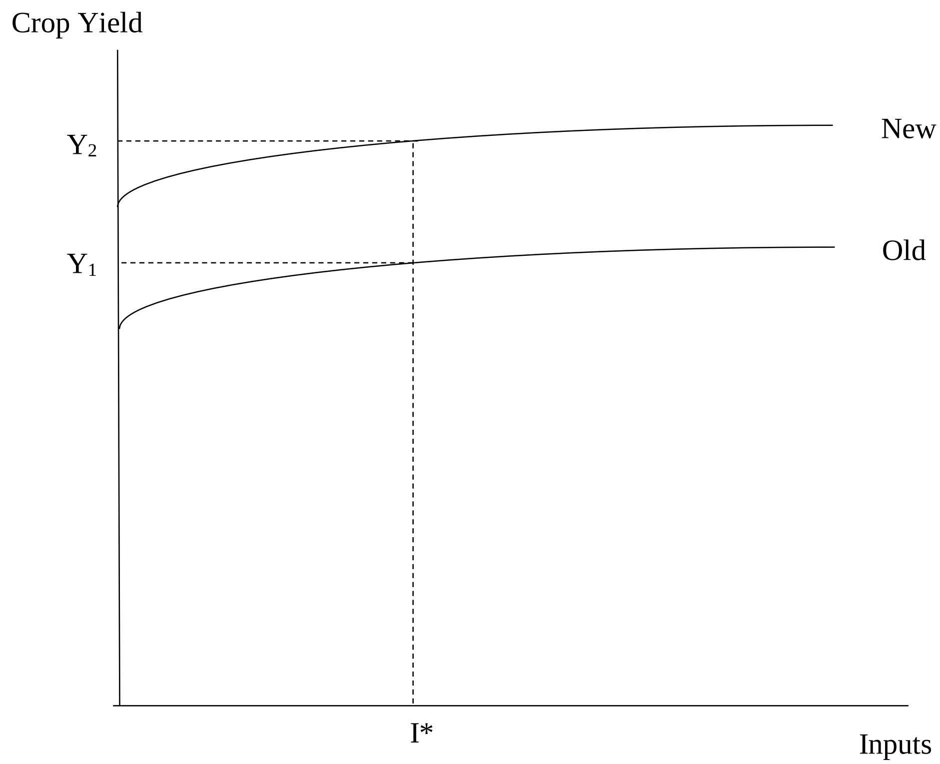

Figure 3.1. Effects of old and new crop varieties on yield.

Another example of technological change is increasing irrigation efficiency. According to Peterson and Ding (2005), subsurface drip irrigation (SDI) proves to be more efficient in water allocation and plant water uptake than center pivot irrigation (LESA, MESA, LEPA) in the SHP of Texas. Therefore, when a producer adopts the SDI system instead of LESA, they may experience a shift in the production curve due to a more efficient use of water by the plants. This shift in the production curve would allow a producer to apply the same amount of irrigation water (Irr^1) to increase yields to Y^2 or reduce the amount of irrigation applied (Irr^2) and produce the same yield (Y^1) as seen in Figure 3.2.

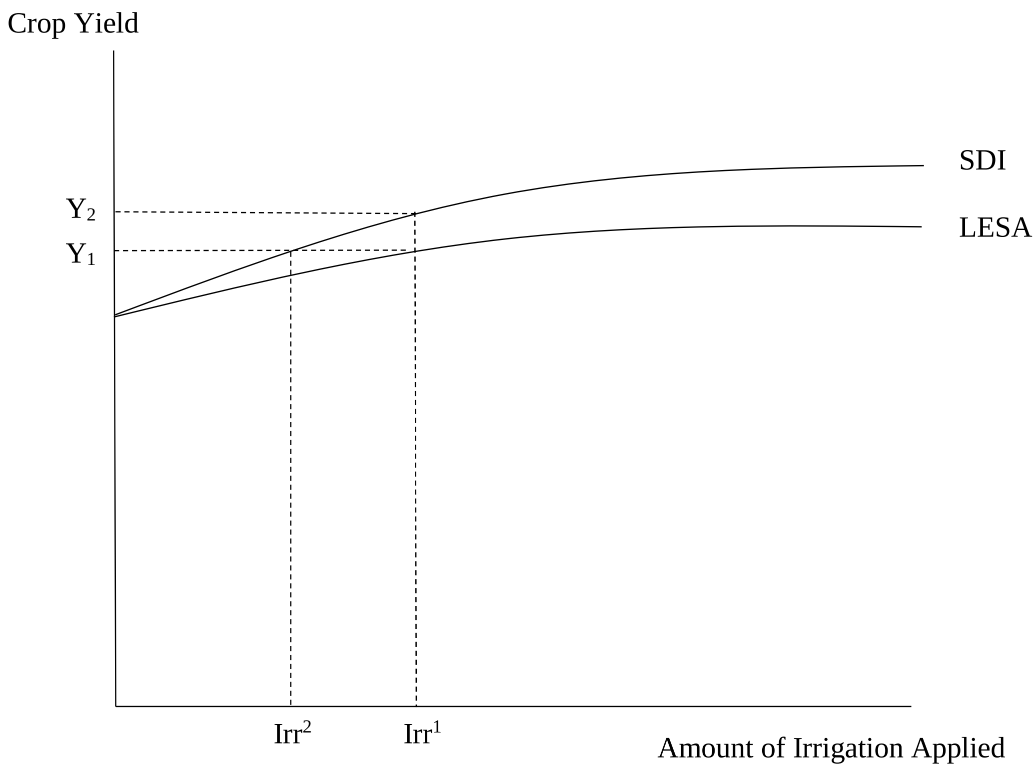

Figure 3.2. Effects of SDI and LESA on irrigation application and yields.

These examples of technological change cause an increase in the total factor productivity and a shift in the production function. The shift in the producer function allows a producer to use the same amount of inputs to produce more output, or reduce the amount of inputs to generate the same amount of output previously produced. Other techniques which reduce soil erosion and water runoff, improve soil nutrients and water holding capacity, etc. also improve the productivity of an operation, especially when used in combination. Due to this shift in the production relationship, a producer would experience increased profit due to the higher level of productivity of their operation. Therefore, technological change is an important factor in the productivity of an operation and is vital for increasing profit.

Optimality

The relationships shown in Figure 3.3 illustrate the effect of adoption of production practices and technologies that increase factor productivity. Figure 3.3 was adapted from Beattie and Taylor (1985) by Mitchell (2014) and illustrates the linkage between the production function and cost-output relationships. The blue curves represent the initial level of production practices and technologies. The black curves represent the adoption of practices and technologies that shift the production relationships as factor productivity increases.

> "Panel (a) shows the production relationship (TPP curve) between the level of input x and output y; panel (b) shows the total value product (TVP) and the total factor cost (c) as a function of x; panel (b′) shows the total variable cost (VC) and total revenue (TR) curves as a function of y; panel (c) shows the marginal factor cost (MFC) and marginal value product (MVP) curves as a function of x; panel (c′) shows the marginal cost (MC) and marginal revenue (MR) curves as a function of y.
>
> The relationships denoted by the blue curves are the initial level of production practices and technologies. The optimal level of output y* is at point A on the TPP curve at input level x* (panel a). The optimal level of input x* is determined where MFC equals MVP at point C (panel c). The optimal level of output, y*, is where MC equals MR at point B (panel c′).

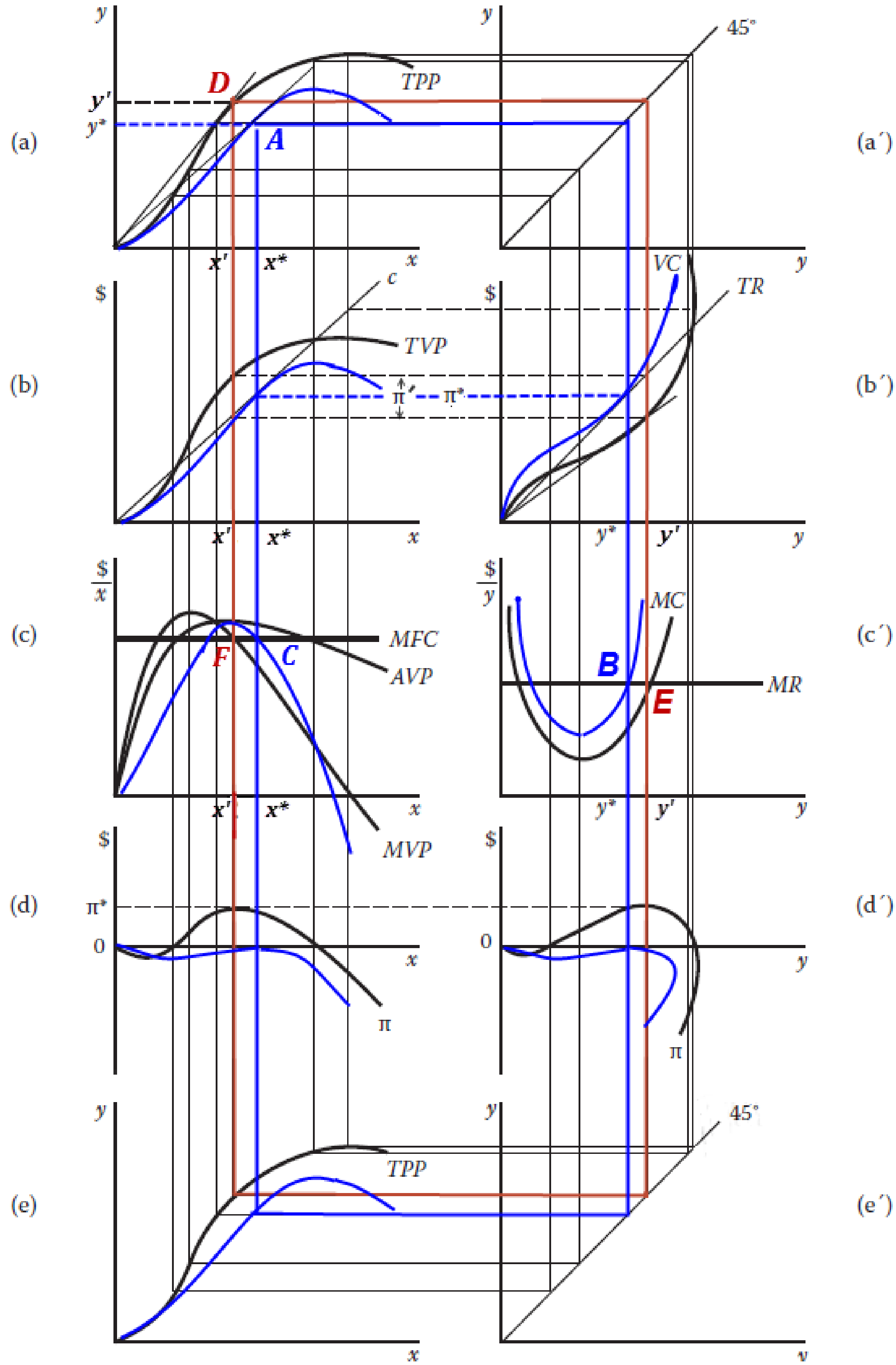

Figure 3.3. Linkage between the production function and cost-output relationship with extensions to marginal conditions (Beattie and Taylor, 1985).

At the optimal level of output y* and input level x*, profit is maximized and is shown as π* (the blue dashed lines in panels (b) and (b′)). In this example, the point of maximum profit is approximately zero. Profit is the difference between the TVP and c curves in panel (b) and the TR and VC curves in panel (b′). A rational producer with a goal of profit maximization would use input level of x* and produce a level of output y*.

Technology adoption and improved production practices in agricultural production may cause the production function in panel (a) to shift upwards (from the blue TPP curve to the black TPP curve) which would increase output at any given level of input and change the optimal level of input use. The optimal level of input is x′, where MFC equals MVP at point F (panel c), resulting in the optimal level of output y′ given by point D on the TPP curve (panel a). The optimal level of output under this scenario is y′, where MC equals MR at point E (panel c′). At the optimal level of output y′ and input level x′, profit is maximized and is shown as π* (the blue dashed line in panels (c) and (c′)). In this example, the point of maximum profit is approximately zero. A producer with a goal of profit maximization would use an input level of x′ and produce a level of output y′ in this scenario. As shown in this scenario, a shift upward in the production function (TPP) increases optimal output from y* to y′, decreases the optimal input level from x* to x′, and increases profit." (Mitchell, 2014)

CHAPTER IV
METHODS AND PROCEDURES

The general objective of this study is to analyze management practices in the SHP of Texas in order to identify sustainable production practices for the area and determine their impact on profit. By using the Fieldprint® Calculator and TAWC Solutions tools, the environmental and economic impact of farming practices in the SHP of Texas can be estimated. The utilization of these tools will allow producers to be more conscientious of the impacts their production practices have on the environment and on the profit of their operation. The data used in this study is from fields of various crop types across eight years of production (2007-2014) in the TAWC project located in the SHP of Texas.

The Texas Alliance for Water Conservation (TAWC) is a collaborative project comprised of agricultural producers in Castro, Crosby, Deaf Smith, Lamb, Lubbock, Parmer, and Swisher counties with the majority of demonstration farms located in Hale and Floyd counties. The project focuses on conserving water while maintaining and improving agricultural production. The data used in this study was from 26 producers in the TAWC project from the years 2007 – 2014, totaling 181, 67, and 29 observations from cotton, corn, and wheat fields, respectively. The fields vary in size from 13 acres to 398 acres and include no-till, strip-till, and conventional tillage operations. Different irrigation methods such as center pivot (LESA, MESA, LEPA), subsurface drip (SDI), and furrow (FUR) irrigation are also used. Producers provide the TAWC with field information on irrigation; tillage operations; chemical input applications of fertilizer, herbicide, insecticide, and harvest aids; and crop yield. Cost and return budgets were developed for each site to estimate the cost of production and profitability. Gross margin, cash receipts less cash costs, was used as the estimation for profit. Fixed costs were not included in the calculations because it is assumed that these costs have a neutral effect on the outcome given that fixed costs are proportional to change in each unit of output.

Data from the TAWC sites was entered into the Fieldprint® Calculator, an analytical tool developed by Field to Market® – The Keystone Alliance for Sustainable Agriculture – which generates values for metrics that measure the sustainability of a given operation. The calculator measures sustainability based on seven metrics: land use (acres/unit of production), irrigation water use (inches/unit of production), energy use (gallons of diesel/unit of production), greenhouse gas emissions (lbs CO_2/unit of production), soil conservation (tons of soil loss/acre/year), soil carbon (index), and water quality (index). The units of production used in the calculator are pounds for cotton and bushels for grains. Currently, the Fieldprint® Calculator can generate sustainability metrics for the following crops: corn, cotton, potatoes, soybeans, and wheat.

Land Use

Land use (acres/unit of production) refers to the production efficiency of a particular field and is directly related to crop yield. If one field produces more yield per acre than another it has a lower land use metric, meaning it is more efficient as it requires less land to produce the same amount of a particular crop. The factor that effects the land use metric is the level of crop yield.

Irrigation Water Use

Irrigation water use (inches/unit of production) is the amount of water applied per unit of crop production. A lower irrigation water use metric means that less irrigation water is used to produce a unit of production. Factors that affect irrigation water use are crop type, the type of irrigation system, irrigation management, soil type, and environmental factors.

Energy Use

Energy use (gallons of diesel/unit of production) accounts for all direct and indirect energy from production inputs used for an operation. Direct energy use is from inputs such as fuel used for irrigation and tillage operations. Indirect energy is energy used in the manufacture and transportation of inputs such as fertilizer and chemicals, and capital assets such as equipment. A lower energy use metric means that less energy is used to produce a unit of production. Factors that affect energy use are the types and levels of production inputs which includes irrigation, fertilizer, and pesticides.

Greenhouse Gas Emissions

Greenhouse gas emissions (lbs CO_2/unit of production) refers to the amount of CO_2 produced and is generally related to direct and indirect energy usage. A lower greenhouse gas emissions metric means that less CO_2 was emitted to produce one unit of production. Generally, there is a high correlation between energy use and greenhouse gas emissions because the production of CO_2 is related to energy use.

Soil Conservation

The soil conservation metric (tons of soil loss/acre/year) accounts for estimated soil erosion in the field due to water and wind. Factors that affect soil erosion are soil type, tillage practices, crop type, the type of irrigation system, and environmental factors. For this study, the soil conservation metric was expressed relative to the soil T value. The T value is soil loss tolerance which is the maximum amount of soil loss in tons/acre/year that can be tolerated and still permit a sustainable level of crop productivity.

Soil Carbon and Water Quality

The soil carbon metric is an index of the level of soil carbon in the soil and the water quality metric is an index that refers to the quality of runoff water at the edge of the field. These metrics could be influenced by crop type, tillage practices, fertilizer and pesticide use, soil type, and topography.

Entering Data into the Fieldprint® Calculator

First, a producer will register their field on www.fieldtomarket.org using their personal information. Once registration is complete, the producer will add a new field under the Field tab on the Start page. Next, they will select the location of their field by entering the state, county, and geographical coordinates (latitude and longitude) of the field. Once the field appears in the map, they will use a tool to select the area in which their field is located as well as enter the size of the field. The Fieldprint® Calculator will then generate the soil information for the selected area. Next, the producer will select the production year for which they are entering information then they will enter various crop information such as: type of crop, planting date, seeding rate, row spacing, tile drainage system, amount of irrigation and rainfall, as well as previous crop planted. The next tab focuses on farm management and the producer will enter information such as: type of tillage system; management system; amount of vegetation present throughout the year; type of integrated pest management used; nutrient application rate; soil condition; dominant application method; application type; and specific information on fertilizer/crop protectant trips including what type of crop protectant and/or fertilizer, the amount of fertilizer used, application timing, and the number of crop protectants used. Currently, the calculator allows the producer to select the type of tillage system used (conventional, strip, ridge, mulch, and no-till) then the producer selects which set of operations best resembles their tillage practices including type and number of tools used. Newer versions of the calculator will allow the producer to select each type of tool used as well as the frequency of use. The producer then enters the travel distance to the point of sale (an average of 10 miles is assumed for TAWC producers) and the fuel type used to transport the product (TAWC assumes diesel for all producers). Next, a producer selects the cotton moisture at ginning (TAWC assumes very dry given the climate of the SHP) or the drying system used (TAWC assumes no drying system). The next section allows a producer to select the number of acres they planted but did not harvest. Last, a producer can select up to three conservation practices used on their field such as grass waterways, cover crops, vegetative barriers, etc. Once all the information is entered, the Fieldprint® Calculator will calculate the sustainability metrics for the field and show how the producer (shaded purple area) compares to state (orange) and national (green) averages on a spidergram seen in Figure 4.1.

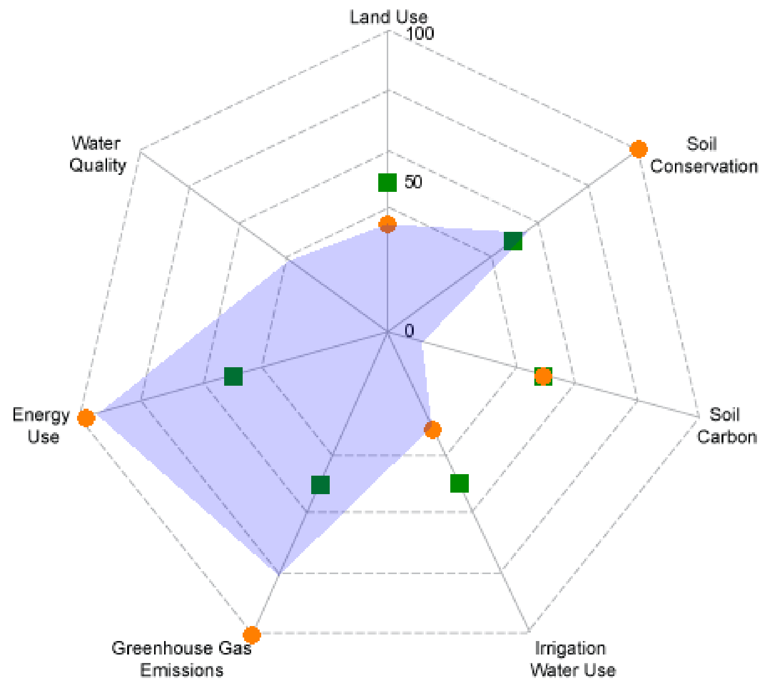

Figure 4.1. Spidergram of a production operation that planted corn in 2012.

<u>Methods</u>

There are four sustainability metrics in the Fieldprint® Calculator that are expressed relative to the unit of crop production: land use, irrigation water use, energy use, and greenhouse gas emissions. For instance, the irrigation metric for cotton is expressed as inches of irrigation per lb of production. Due to this, the metric values become smaller as resource use becomes more efficient or the production of externalities such as greenhouse gas emissions are reduced. Since cotton is a joint product comprised of lint and seed, the Fieldprint® Calculator computes values based on a lint equivalent yield (LEY). The LEY is calculated based on lint yield providing 83% of revenues ans seed yield providing 17% of revenues. For example, a lint yield of 1,300 lbs would be converted to a LEY of 1,566 lbs to account for the seed yield. For crops such as corn and wheat, yield does not need to be adjusted and is expressed in bushels.

The data was evaluated two different ways using the data output file generated by the Fieldprint® Calculator. First, raw numbers were used and run against gross margin. Second, index values were created and run against gross margin. The sustainability metrics were each converted to an index value based on the mean value of each metric for the 181, 67, and 29 observations for cotton, corn, and wheat, respectively. By converting the metrics to an index value, the units were standardized for each metric. The results obtained from the raw data appear in the appendix, by only the results using the index values were evaluated in the study since the results are considerably easier to analyze and discuss. A regression analysis using the ordinary least squares (OLS) method was performed where gross margin was the dependent variable, and the independent variables consisted of the index value or raw value for each metric, as well as the dummy variables for each year (2007 – 2014), irrigation system type (LESA, LEPA, FUR, MESA, and SDI), and tillage type (conventional, minimum (MIN), and no-till (NT)). Minimum tillage is defined as any operation that uses only one invasive tillage practice (disc or lister) and three or fewer less invasive tillage practices (coulter, rodweeder, etc.), or any operation that uses two invasive tillage practices only. Any operation that uses more tillage was classified as a conventional tillage operation.

Another set of models were run with irrigation systems and tillage systems as the independent variables and the sustainability metrics as dependent variables. Six models were run for each crop which included the same independent variables but six different dependent variables: the average of all five sustainability metrics, land use, irrigation water use, energy use, greenhouse gas emissions, and soil conservation. As a result, the impact of production years and operational systems on the sustainability of an operation can be evaluated. All constructed models were run in SAS Enterprise Guide 6.1 to determine statistical values and model parameters.

CHAPTER V
RESULTS AND DISCUSSION

Effects of Sustainability Metrics on Gross Margin

Out of the seven metrics available in the Fieldprint® Calculator, only five were evaluated in this study. Since information on the method of calculation of the Soil Carbon index and Water Quality index is limited, and the importance of their effect on gross margin is unknown, these metrics were not included the study. Land use, irrigation water use, energy use, and soil conservation, as well as dummy variables which represent the years of production, production sites, type of crop planted, type of irrigation system, and type of tillage system were specified as independent variables. Gross margin was specified as the dependent variable. The specified equations were estimated using Ordinary Least Squares (OLS) Regression with SAS Enterprise Guide 6.1. The sustainability metrics were converted to an index based on the mean value of each metric across all observations for a particular crop type. The conversion of the metrics to an index value standardized the units for each metric. Only sites that produced and harvested a crop were included in the study; sites that collected insurance due to a failed crop were not included. Three crops were evaluated in the study: corn, cotton, and wheat.

The results indicated that there was approximately a 95% correlation between the energy use (ENG) and greenhouse gas emissions (GHG) variables. Due to the high level of correlation, only one variable was used in the model, energy use (ENG). There was a correlation of approximately 55% between the energy use (ENG) and irrigation water use (IRR) variables. However, it is important to keep both variables included in the model as both variables should have an effect on gross margin (GM). In the model, a squared value of the energy use variable, ENG2, was included to account for diminishing marginal returns. The model was run using a squared value for irrigation water use as well, but skewed the results when it was included in the model. Due to this, it is likely that if producers are over irrigating, it is not enough for them to enter stage III of production. Therefore, there is no reason to account for diminishing marginal returns in regards to irrigation water use. It was determined that the effects of the soil conservation metric on gross margin would be long-term effects, so it was removed from the model as there are not enough years in the data set for the metric to have noticeable effects on gross margin.

The construction of the index values for the sustainability metrics is such that an improvement in sustainability, for example a decrease in irrigation per pound of cotton produced relative to the mean across all cotton observations, would decrease the index value. Therefore, the interpretation of a change in index values for the sustainability metrics is that an increased index value is a negative change in the sustainability metric and a decreased index value is a positive change in the sustainability metric.

Wheat

There were 29 observations for wheat over eight years of production. Prices for wheat varied among production years and were related to prices received in the Southern High Plains of Texas region. The wheat prices for each year can be found in Appendix C in Table A.1. The observations were run in SAS to determine parameter estimates and variable significance. The model evaluated in SAS appears below.

(5.1) $$GM = \beta_1 + \beta_2{*}LU + \beta_3{*}IRR + \beta_4{*}ENG + \beta_5{*}ENG2 + \beta_6{*}D8 + \beta_7{*}D9 + \beta_8{*}D10 + \beta_9{*}D11 + \beta_{10}{*}D12 + \beta_{11}{*}D13 + \beta_{12}{*}D14$$

Where:

GM = gross margin per acre of each field
LU = the index value of the land use indicators
IRR = the index value of the irrigation water use indicators
ENG = the index value of the energy use indicators
ENG2 = the squared value of the ENG metric
D8 = dummy variable for the 2008 production year
D9 = dummy variable for the 2009 production year
D10 = dummy variable for the 2010 production year
D11 = dummy variable for the 2011 production year
D12 = dummy variable for the 2012 production year
D13 = dummy variable for the 2013 production year
D14 = dummy variable for the 2014 production year

*2007 was the base production year

Table 5.1. Parameter Estimates for Gross Margin per Acre of Wheat.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	164.86591	73.33558	2.25	0.0381
LU	-1.02663	0.40866	-2.51	0.0224
IRR	-0.08591	0.69140	-0.12	0.9026
ENG	-0.59761	1.36403	-0.44	0.6668
ENG2	0.00073757	0.00425	0.17	0.8642
D8	221.30735	54.45549	4.06	0.0008
D9	35.91041	55.73945	0.64	0.5280
D10	-14.96803	61.69662	-0.24	0.8112
D11	-2.44852	76.66776	-0.03	0.9749
D12	83.87523	58.95548	1.42	0.1729
D13	-37.61103	64.72415	-0.58	0.5688
D14	-67.53781	101.24700	-0.67	0.5137

Table 5.1 gives the parameter estimates for gross margin per acre of wheat expressed as a function of land use, irrigation, energy, and production years. The model had an adjusted R^2 of 0.6979. The coefficient for the Land Use (LU) variable of -1.02663 had the expected sign and was significant at the 95% confidence interval. A one unit decrease in the LU index would have a positive change on gross margin of $1.03 per acre. The irrigation (IRR) and energy use (ENG) variables were not significant. The dummy variables for years were included in the model to account for the effects of factors such as price received and environmental factors. The results for the model for wheat are inconclusive relative to the effects of the sustainability metrics on gross margin. If more observations had been available, it is possible that the model would have presented more significant results.

Corn

There were 67 corn observations over eight years of production from 2007 through 2014. Prices for corn vary among production years and are related to prices received in the Southern High Plains of Texas region. Both corn for food and grain were used in the observations, but corn silage was excluded. The price received for corn grain was used as the standard price among all corn observations. The corn prices for each year can be found in Appendix A in Table A.1. The corn observations were evaluated using SAS to determine parameter estimates and significance.

Model 1 shown in equation 5.2 expresses gross margin for corn as a function of LU, IRR, ENG, ENG2, as well as, dummy variables for years, irrigation systems LEPA, MESA and SDI, and tillage systems minimum tillage (MIN) and no tillage (NT).

$$\textbf{(5.2)}\quad GM = \beta_1 + \beta_2*LU + \beta_3*IRR + \beta_4*ENG + \beta_5*ENG2 + \beta_6*D8 + \beta_7*D9 + \beta_8*D10 + \beta_9*D11 + \beta_{10}*D12 + \beta_{11}*D13 + \beta_{12}*D14 + \beta_{13}*LEPA + \beta_{14}*MESA + \beta_{15}*SDI + \beta_{16}*MIN + \beta_{17}*NT$$

Where:

GM = gross margin per acre of each field
LU = index value of the land use indicators
IRR = index value of the irrigation water use indicators
ENG = index value of the energy use indicators
ENG2 = the squared value of the ENG index
D7 = dummy variable for the 2007 production year
D8 = dummy variable for the 2008 production year
D9 = dummy variable for the 2009 production year
D11 = dummy variable for the 2011 production year
D12 = dummy variable for the 2012 production year
D13 = dummy variable for the 2013 production year
D14 = dummy variable for the 2014 production year
LEPA = low energy precision application irrigation system
MESA = mid elevation spray application irrigation system
SDI = subsurface drip irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*2010 was the base production year
*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.2. Parameter Estimates for Corn Model 1.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	1137.40641	166.83137	6.82	<.0001
LU	-1.71585	1.10773	-1.55	0.1277
IRR	-0.68371	1.17285	-0.58	0.5625
ENG	-7.20417	2.20003	-3.27	0.0019
ENG2	0.01700	0.00494	3.44	0.0012
D7	-217.80021	124.14680	-1.75	0.0855
D8	274.92994	107.60764	2.55	0.0137
D9	-53.08099	123.73953	-0.43	0.6698
D11	-4.84098	170.63693	-0.03	0.9775
D12	46.75796	111.07211	0.42	0.6756
D13	165.10838	100.03108	1.65	0.1051
D14	-141.08373	101.39641	-1.39	0.1703
LEPA	-143.59742	82.86289	-1.73	0.0893
MESA	76.59378	116.61290	0.66	0.5143
SDI	-72.90480	72.72287	-1.00	0.3209
MIN	71.73520	74.95876	0.96	0.3432
NT	-124.70139	116.18332	-1.07	0.2883

Table 5.2 presents the parameter estimates for gross margin per acre of corn expressed as a function of land use, irrigation, energy, irrigation system types, tillage systems and years. The adjusted R^2 for the model is 0.4071. The coefficients for the land use (LU), irrigation (IRR) and energy use (ENG) variables all have the expected sign, however, only the ENG variable was significant at the 90% confidence interval. A one unit decrease in the ENG index would have a positive change on gross margin of $6.34 per acre. The variables for irrigation system type indicated that the LEPA system had a significantly negative impact on gross margin with a coefficient of -152.42, with the LESA as the base system. The MESA and SDI systems were not significantly different from the LESA system. The tillage system variables of minimum tillage (MIN) and no

till (NT) were not significantly different from the base system of conventional tillage. The dummy variables for years were included in the model to account for the effects of factors such as price received and environmental factors.

Model 2 shown in equation 5.3 was specified with gross margin as the dependent variable and independent variables of LU, IRR, ENG, ENG2, as well as, dummy variables for years and production sites. Given that the data is an unbalanced panel data set, the production site variables and year variables were included to account for the fixed effects across the 17 corn sites and eight years of production.

$$\textbf{(5.3)}\quad \mathbf{GM = \beta1 + \beta2{*}LU + \beta3{*}IRR + \beta4{*}ENG + \beta5{*}ENG2 + \beta6{*}D7 + \beta7{*}D8 + \beta8{*}D9 + \beta9{*}D11 + \beta10{*}D12 + \beta11{*}D13 + \beta12{*}D14 + \beta13{*}Site\ A + \beta14{*}\ Site\ B + \beta15{*}\ Site\ C + \beta16{*}\ Site\ D + \beta17{*}\ Site\ E + \beta18{*}\ Site\ F + \beta19{*}\ Site\ G + \beta20{*}\ Site\ H + \beta21{*}\ Site\ I + \beta22{*}\ Site\ J + \beta23{*}\ Site\ K + \beta24{*}\ Site\ L + \beta25{*}\ Site\ M + \beta26{*}\ Site\ N + \beta27{*}\ Site\ O + \beta28{*}\ Site\ P + \beta29{*}\ Site\ Q}$$

Where:

GM = gross margin per acre of each field
LU = index value of the land use indicators
IRR = index value of the irrigation water use indicators
ENG = index value of the energy use indicators
ENG2 = the squared index value of the ENG metric
D7 = dummy variable for the 2007 production year
D8 = dummy variable for the 2008 production year
D9 = dummy variable for the 2009 production year
D11 = dummy variable for the 2011 production year
D12 = dummy variable for the 2012 production year
D13 = dummy variable for the 2013 production year
D14 = dummy variable for the 2014 production year
Sites A – Q = all production operations that produced corn one or more years

*2010 was the base production year
*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.3. Parameter Estimates for Corn Model 2.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	1337.60242	230.84504	5.79	<.0001
LU	-1.83967	1.34312	-1.37	0.1788
IRR	-1.43297	1.10532	-1.30	0.2026
ENG	-7.69498	3.85223	-2.00	0.0530
ENG2	0.01871	0.00928	2.02	0.0510
D7	-257.54099	125.37897	-2.05	0.0469
D8	243.22713	107.80304	2.26	0.0299
D9	-61.74431	123.82812	-0.50	0.6209
D11	142.37957	177.68309	0.80	0.4279
D12	286.72998	124.49447	2.30	0.0268
D13	232.58884	114.46819	2.03	0.0492
D14	-71.95137	94.65646	-0.76	0.4519
Site A	-378.07616	146.67472	-2.58	0.0140
Site B	-217.02124	109.99877	-1.97	0.0558
Site C	-95.59282	129.37049	-0.74	0.4645
Site D	35.68897	620.26209	0.06	0.9544
Site E	-31.97071	118.18069	-0.27	0.7882
Site F	-186.06384	143.71752	-1.29	0.2033
Site G	-33.80201	144.65405	-0.23	0.8165
Site H	-101.81574	229.10432	-0.44	0.6593
Site I	-9.23136	115.55974	-0.08	0.9367
Site J	-127.24253	132.22337	-0.96	0.3420
Site K	-198.37838	233.83591	-0.85	0.4015
Site L	-251.89633	187.85484	-1.34	0.1879
Site M	-616.09760	158.54999	-3.89	0.0004
Site N	-314.38616	165.75445	-1.90	0.0655
Site O	-396.81127	171.69861	-2.31	0.0263
Site P	-190.83787	164.81053	-1.16	0.2541
Site Q	-279.70002	157.36640	-1.78	0.0835

Table 5.3 presents the parameter estimates for gross margin per acre of corn expressed as a function of land use, irrigation, energy, production years, and production sites. The adjusted R^2 for the model is 0.5441. The coefficients for the land use (LU), irrigation water use (IRR), and energy use (ENG) all have the expected sign, however, only the ENG variable was significant at the 90% confidence interval. A one unit decrease in the ENG index would have a positive change on gross margin of $7.69 per acre. The dummy variables for years were included in the model to account for the effects of factors such as price received and environmental factors. The dummy variables for sites were included in the model to account for the fixed effects of various production operations. Sites M and N are owned and operated by the same producer meaning that the differences from the base Site X could be due to varied management practices.

Cotton

There were 181 cotton observations over eight years of production from 2007 through 2014. Prices for cotton vary among production years and are related to prices received in the Southern High Plains of Texas region. The cotton prices for each year can be found in Appendix B in Table B.1. The cotton observations were evaluated using SAS to determine parameter estimates and significance.

Model 1 shown in equation 5.4 expresses gross margin for cotton as a function of LU, IRR, ENG, ENG2, as well as, dummy variables for years, irrigation systems LEPA, FUR, MESA, and SDI, and tillage systems minimum tillage (MIN) and no tillage (NT).

(5.4) $$GM = \beta_1 + \beta_2{*}LU + \beta_3{*}IRR + \beta_4{*}ENG + \beta_5{*}ENG2 + \beta_6{*}D8 + \beta_7{*}D9 + \beta_8{*}D10 + \beta_9{*}D11 + \beta_{10}{*}D12 + \beta_{11}{*}D13 + \beta_{12}{*}D14 + \beta_{13}{*}LEPA + \beta_{14}{*}FUR + \beta_{15}{*}MESA + \beta_{16}{*}SDI + \beta_{17}{*}MIN + \beta_{18}{*}NT$$

Where:

GM = gross margin per acre of each field
LU = index value of the land use indicators
IRR = index value of the irrigation water use indicators
ENG = index value of the energy use indicators
ENG2 = the squared index value of the ENG metric
D8 = dummy variable for the 2008 production year
D9 = dummy variable for the 2009 production year
D10 = dummy variable for the 2010 production year
D11 = dummy variable for the 2011 production year
D12 = dummy variable for the 2012 production year
D13 = dummy variable for the 2013 production year
D14 = dummy variable for the 2014 production year
LEPA = low energy precision application (LEPA) irrigation system
FUR = furrow (FUR) irrigation system
MESA = mid elevation spray application (MESA) irrigation system
SDI = subsurface drip (SDI) irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*2007 was the base production year
*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.4. Parameter Estimates for Cotton Model 1.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	1055.22356	61.64177	17.12	<.0001
LU	-4.29439	0.43280	-9.92	<.0001
IRR	-1.03141	0.52466	-1.97	0.0510
ENG	-3.65781	0.98680	-3.71	0.0003
ENG2	0.00845	0.00173	4.87	<.0001
D8	-122.03381	48.76619	-2.50	0.0133
D9	-57.52090	46.67608	-1.23	0.2196
D10	189.22138	46.89313	4.04	<.0001
D11	517.22363	60.02687	8.62	<.0001
D12	508.21567	48.97213	10.38	<.0001
D13	284.64708	46.21296	6.16	<.0001
D14	-64.93664	45.63141	-1.42	0.1566
LEPA	-33.52677	35.18187	-0.95	0.3420
FUR	-27.15769	44.28964	-0.61	0.5406
MESA	17.66472	36.51475	0.48	0.6292
SDI	23.71650	32.32672	0.73	0.4642
MIN	-35.54396	27.77280	-1.28	0.2024
NT	-16.97317	39.93224	-0.43	0.6714

Table 5.4 presents the parameter estimates for gross margin per acre of cotton expressed as a function of land use, irrigation water use, energy use, irrigation system types, tillage systems, and production years. The adjusted R^2 for the model is 0.7619. The coefficients for the land use (LU), irrigation water use (IRR), and energy use (ENG) all have the expected sign. The land use and energy use variables were both significant at the 99% confidence interval and the irrigation water use variable was significant at the 95% confidence interval. A one unit decrease in the LU variable would have a positive change on gross margin of $4.29. A one unit decrease in the IRR variable would have a positive change on gross margin of $1.03. A one unit decrease in the ENG variable would have a

positive change on gross margin of $3.66. The variables for irrigation system type and tillage systems were not significantly from the bases LESA and conventional tillage, respectively. The dummy variables for production years were included in the model to account for the effects of factors such as price received and environmental factors.

Model 2 shown in equation 5.5 was specified with gross margin as the dependent variable and independent variables of LU, IRR, ENG, ENG2, as well as, dummy variables for years and production sites. Given that the data is an unbalanced panel data set, the production site variables and year variables were included to account for the fixed effects across the 33 cotton sites and eight years of production.

$$\begin{aligned}
(5.5) \quad GM = {} & \beta_1 + \beta_2{*}LU + \beta_3{*}IRR + \beta_4{*}ENG + \beta_5{*}ENG2 + \beta_6{*}D8 + \beta_7{*}D9 + \\
& \beta_8{*}D10 + \beta_9{*}D11 + \beta_{10}{*}D12 + \beta_{11}{*}D13 + \beta_{12}{*}D14 + \beta_{13}{*}Site\ A + \\
& \beta_{14}{*}\ Site\ B + \beta_{15}{*}\ Site\ C + \beta_{16}{*}\ Site\ D + \beta_{17}{*}\ Site\ E + \beta_{18}{*}\ Site\ F + \\
& \beta_{19}{*}\ Site\ G + \beta_{20}{*}\ Site\ H + \beta_{21}{*}\ Site\ I + \beta_{22}{*}\ Site\ J + \beta_{23}{*}\ Site\ K + \\
& \beta_{24}{*}\ Site\ L + \beta_{25}{*}\ Site\ M + \beta_{26}{*}\ Site\ N + \beta_{27}{*}\ Site\ O + \beta_{28}{*}\ Site\ P + \\
& \beta_{29}{*}\ Site\ Q + \beta_{30}{*}\ Site\ R + \beta_{31}{*}\ Site\ S + \beta_{32}{*}\ Site\ T + \beta_{33}{*}\ Site\ U + \\
& \beta_{34}{*}\ Site\ V + \beta_{35}{*}\ Site\ W + \beta_{36}{*}\ Site\ X + \beta_{37}{*}\ Site\ Y + \beta_{38}{*}\ Site\ Z + \\
& \beta_{39}{*}\ Site\ AA + \beta_{40}{*}\ Site\ AB + \beta_{41}{*}\ Site\ AC + \beta_{42}{*}\ Site\ AD + \\
& \beta_{43}{*}\ Site\ AE + \beta_{44}{*}\ Site\ AF + \beta_{45}{*}\ Site\ AG
\end{aligned}$$

Where:

GM = gross margin per acre of each field
LU = index value of the land use indicators
IRR = index value of the irrigation water use indicators
ENG = index value of the energy use indicators
ENG2 = the squared index value of the ENG metric
D8 = dummy variable for the 2008 production year
D9 = dummy variable for the 2009 production year

D10 = dummy variable for the 2010 production year
D11 = dummy variable for the 2011 production year
D12 = dummy variable for the 2012 production year
D13 = dummy variable for the 2013 production year
D14 = dummy variable for the 2014 production year
Sites A – AG = all production operations that produced cotton one or more years

*2007 was the base production year
*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.5. Parameter Estimates for Cotton Model 2.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	1108.14471	65.70809	16.86	<.0001
LU	-3.35803	0.50316	-6.67	<.0001
IRR	-1.10658	0.54520	-2.03	0.0443
ENG	-5.15042	1.07497	-4.79	<.0001
ENG2	0.01082	0.00178	6.07	<.0001
D8	-145.98950	49.44423	-2.95	0.0037
D9	-100.99847	47.28535	-2.14	0.0345
D10	156.37536	47.77788	3.27	0.0013
D11	508.46841	62.85195	8.09	<.0001
D12	508.89323	52.55289	9.68	<.0001
D13	281.78410	47.29290	5.96	<.0001
D14	-62.71146	48.25154	-1.30	0.1959
Site A	-59.35398	83.57534	-0.71	0.4788
Site B	-4.34463	71.83054	-0.06	0.9519
Site C	-17.33904	61.19052	-0.28	0.7773
Site D	-154.33104	58.36206	-2.64	0.0091
Site E	-95.60166	77.97964	-1.23	0.2223
Site F	68.99349	66.36750	1.04	0.3004
Site G	95.33572	67.99072	1.40	0.1631
Site H	-24.74902	50.17289	-0.49	0.6226
Site I	-56.05652	57.45118	-0.98	0.3309
Site J	14.87913	48.37897	0.31	0.7589
Site K	-11.99285	89.76938	-0.13	0.8939

Table 5.5. Parameter Estimates for Cotton Model 2 (Continued).

Site L	-136.68223	94.43784	-1.45	0.1501
Site M	-80.58811	58.35910	-1.38	0.1696
Site N	143.02300	75.59339	1.89	0.0606
Site O	-77.27621	79.90724	-0.97	0.3352
Site P	9.29175	67.33624	0.14	0.8905
Site Q	-33.82120	153.32891	-0.22	0.8258
Site R	146.58841	109.56858	1.34	0.1832
Site S	-50.58243	91.75826	-0.55	0.5824
Site T	155.08960	62.05536	2.50	0.0136
Site U	-47.43320	71.99875	-0.66	0.5111
Site V	138.47999	111.70828	1.24	0.2172
Site W	-137.27593	79.56405	-1.73	0.0867
Site X	-33.07610	107.47877	-0.31	0.7587
Site Y	150.50743	149.63212	1.01	0.3163
Site Z	-19.49884	107.38520	-0.18	0.8562
Site AA	-55.24952	111. 97292	-0.49	0.6225
Site AB	-211.80525	110.54649	-1.92	0.0575
Site AC	-194.14225	111.17357	-1.75	0.0830
Site AD	-158.80676	110.01689	-1.44	0.1512
Site AE	-184.79928	93.82224	-1.97	0.0509
Site AF	-97.74106	149.51555	-0.65	0.5144
Site AG	-157.60700	150.89784	-1.04	0.2981

Table 5.5 presents the parameter estimates for gross margin per acre of cotton expressed as a function of land use, irrigation water use, energy use, production years, and production sites. The adjusted R^2 for the model is 0.7934. The coefficients for the land use (LU), irrigation water use (IRR), and energy use all have the expected signs. The land use and energy use variables were both significant at the 99% confidence level and the irrigation water use variable was significant at the 95% confidence level. A one unit decrease in the land use variable would have a positive change on gross margin of $3.36. A one unit decrease in the irrigation water use variable would have a positive change on

gross margin of $1.11. A one unit decrease in the energy use variable would have a positive change on gross margin of $5.15. The dummy variables for years were included in the model to account for the effects of factors such as price received and environmental factors. The dummy variables for production sites were to account for the effects of field attributes and management practices. Sites D and W, sites N and T, and sites AB and AE belong to producers 1, 2, and 3, respectively. Producer 1 had high variable costs each year of production and Producer 2 had consistently high yields across all year of production. Given that these producers each have two sites that were significantly different from the base site AF, it is an indication that individual management practices may have affected gross margins.

Effects of Irrigation and Tillage Systems on Sustainability Metrics

Corn

To determine the effects of production operation systems and practices on the sustainability metrics, all irrigation and tillage systems were used as independent variables with the sustainability metrics from the Fieldprint® Calculator as the dependent variables. The systems were run against the indexes of the five sustainability metrics from the calculator: land use, irrigation water use, energy use, greenhouse gas emissions, and soil conservation; as well as the average index of all five sustainability metrics. Only the model with the land use index as the dependent variable presented significant results, so it is the only one discussed. Since production systems do not change from year to year, the variables in the model account for any variation that may occur in production years, therefore, production years were not included as independent variables.

Equation 5.6 expressed the land use (LU) index for corn as a function of irrigation systems LEPA, MESA, and SDI, and tillage systems minimum tillage (MIN) and no tillage (NT).

(5.6) $$LU = \beta_1 + \beta_2*LEPA + \beta_3*MESA + \beta_4*SDI + \beta_5*MIN + \beta_6*NT$$

Where:

LU = index value of the land use indicators
LEPA = low energy precision application (LEPA) irrigation system
MESA = mid elevation spray application (MESA) irrigation system
SDI = subsurface drip (SDI) irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.6. Parameter Estimates for the Land Use (LU) Index for Corn.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	82.84773	13.01156	6.37	<.0001
LEPA	2.08436	20.43227	0.10	0.9191
MESA	-10.32278	27.64354	-0.37	0.7101
SDI	32.85639	17.49201	1.88	0.0651
MIN	22.34999	15.15410	1.47	0.1454
NT	8.12272	25.98485	0.31	0.7557

Table 5.6 presents the parameter estimates for the land use (LU) index for corn expressed as a function of irrigation system types and tillage systems. The adjusted R^2 for the model is 0.0152. The SDI variable was significant at the 90% confidence level. SDI irrigation systems have a land use index of 32.86 when compared to the base irrigation

system LESA. Since the main driver for the land use variable is yield and a smaller index value is better, it can be concluded that a SDI system results in lower yields for corn crops when compared to the base irrigation system LESA. The magnitude and sign of the SDI variable was an unexpected result. The LEPA and MESA irrigation systems are not significantly different than the base system LESA. Minimum tillage (MIN) and no tillage (NT) are not significantly different from the base, conventional tillage.

Cotton

To determine the effects of production operation systems on sustainability metrics for cotton operations, all irrigation and tillage systems were used as independent variables with the sustainability metrics from the Fieldprint® Calculator as the dependent variables. The systems were run against the average sustainability index for a producer, land use, irrigation water use, energy use, greenhouse gas emissions, and soil conservation. Since production systems do not change from year to year, the variables in the model already account for any variation that may occur in production years, therefore, production years were not included as independent variables.

Equation 5.7 was specified with the land use (LU) index for cotton as the dependent variable and independent variables of irrigation systems LESA, FUR, MESA, and SDI, as well as tillage systems minimum tillage (MIN) and no tillage (NT).

(5.7) $$\mathbf{LU = \beta_1 + \beta_2{*}LEPA + \beta_3{*}FUR + \beta_4{*}MESA + \beta_5{*}SDI + \beta_6{*}MIN + \beta_7{*}NT}$$

Where:

LU = index value of the land use indicators
LEPA = low energy precision application (LEPA) irrigation system

MESA = mid elevation spray application (MESA) irrigation system
SDI = subsurface drip (SDI) irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.7. Parameter Estimates for the Land Use (LU) Index for Cotton.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	95.99878	6.88065	13.95	<.0001
LEPA	-6.79106	9.30962	-0.73	0.4667
FUR	28.66038	11.27394	2.54	0.0119
MESA	23.67502	9.51809	2.49	0.0138
SDI	-7.30667	8.74076	-0.84	0.4043
MIN	-3.99077	7.28041	-0.55	0.5843
NT	3.72620	10.73260	0.35	0.7289

Table 5.7 presents the parameter estimates for the land use (LU) index for cotton expressed as a function of irrigation systems LESA, MESA, FUR, and SDI as well as tillage systems minimum tillage (MIN) and no tillage (NT). The adjusted R^2 for the model is 0.0837. The FUR and MESA variables are significant at the 95% confidence level. Furrow and MESA irrigation systems have higher sustainability indexes for land use than the base irrigation system LESA. Furrow and MESA irrigation systems had a land use index value of 28.66 and 23.68 when compared to the base system LESA, respectively. Due to this, it can be concluded that furrow and MESA irrigation systems have a negative effect on yield when compared to LESA irrigation systems. LEPA and SDI are not significantly different than the base system LESA. Minimum tillage (MIN)

and no-till (NT) are not significantly different from the base, conventional tillage. Price and production variability is captured in the independent variables.

Equation 5.8 was specified with the irrigation water use (IRR) index for cotton as the dependent variable and independent variables of irrigation systems LESA, FUR, MESA, and SDI, as well as tillage systems minimum tillage (MIN) and no tillage (NT).

(5.8) $\mathbf{IRR = \beta_1 + \beta_2{*}LEPA + \beta_3{*}FUR + \beta_4{*}MESA + \beta_5{*}SDI + \beta_6{*}MIN + \beta_7{*}NT}$

Where:

IRR = index values of the irrigation water use indicators
LEPA = low energy precision application (LEPA) irrigation system
MESA = mid elevation spray application (MESA) irrigation system
SDI = subsurface drip (SDI) irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.8. Parameter Estimates for the Irrigation Water Use (IRR) Index for Cotton.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	97.26029	10.85882	8.96	<.0001
LEPA	-5.08275	14.69214	-0.35	0.7298
FUR	38.49179	17.79216	2.16	0.0319
MESA	-3.05198	15.02114	-0.20	0.8392
SDI	-13.92217	13.79438	-1.01	0.3142
MIN	6.91319	11.48970	0.60	0.5482
NT	7.27112	16.93784	0.43	0.6682

Table 5.8 presents the parameter estimates for the irrigation water use (IRR) index for cotton expressed as a function of irrigation system types and tillage systems. The adjusted R^2 for the model is 0.0183. The FUR variable is significant at a 95% confidence level. A furrow irrigation system has an irrigation water use index value of 38.49 when compared to the base irrigation system LESA. Furrow irrigation systems have significantly higher sustainability indexes than LESA irrigation systems, which indicates they are considerably less efficient in regards to input per unit output of irrigation water. The LEPA, MESA, and SDI irrigation systems are not significantly different than the base system LESA. The minimum tillage (MIN) and no tillage (NT) systems are not significantly different from the base, conventional tillage.

Equation 5.9 was specified with the energy use (ENG) index for cotton as the dependent variable and independent variables of irrigation systems LESA, FUR, MESA, and SDI, as well as tillage systems minimum tillage (MIN) and no tillage (NT).

$$\textbf{(5.9)} \quad \mathbf{ENG = \beta_1 + \beta_2{*}LEPA + \beta_3{*}FUR + \beta_4{*}MESA + \beta_5{*}SDI + \beta_6{*}MIN + \beta_7{*}NT}$$

Where:

ENG = index value of the energy use indicators
LEPA = low energy precision application (LEPA) irrigation system
MESA = mid elevation spray application (MESA) irrigation system
SDI = subsurface drip (SDI) irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.9. Parameter Estimates for the Energy Use (ENG) Index for Cotton.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	98.59168	9.24129	10.67	<.0001
LEPA	1.43611	12.50360	0.11	0.9087
FUR	29.92739	15.14185	1.98	0.0497
MESA	3.25776	12.78360	0.25	0.7991
SDI	-12.78550	11.73958	-1.09	0.2776
MIN	-3.71543	9.77820	-0.38	0.7044
NT	9.37918	14.41479	0.65	0.5161

Table 5.9 presents the parameter estimates for the energy use (ENG) index for cotton expressed as a function of irrigation system types and tillage systems. The adjusted R^2 for the model is 0.0190. The FUR variable is significant at a 95% confidence level. Furrow irrigation systems had an energy use index value of 29.93 when compared to the base irrigation system LESA. Given the results, furrow irrigation systems use more energy in terms of input per unit output than LESA irrigation systems, making them less efficient. The LEPA, MESA, and SDI irrigation systems are not significantly different from the base system LESA. Minimum tillage and no tillage systems are not significantly different from the base, conventional tillage.

Equation 5.10 was specified with the soil conservation (SC) index for cotton as the dependent variable and independent variables of irrigation systems LESA, FUR, MESA, and SDI, as well as tillage systems minimum tillage (MIN) and no tillage (NT).

$$\textbf{(5.10)}\quad SC = \beta_1 + \beta_2*LEPA + \beta_3*FUR + \beta_4*MESA + \beta_5*SDI + \beta_6*MIN + \beta_7*NT$$

Where:

SC = index value of the soil conservation indicators

LEPA = low energy precision application (LEPA) irrigation system
MESA = mid elevation spray application (MESA) irrigation system
SDI = subsurface drip (SDI) irrigation system
MIN = minimum tillage system
NT = no-till tillage system

*low elevation spray application (LESA) was the base irrigation system
*conventional tillage was the base tillage system

Table 5.10. Parameter Estimates for the Soil Conservation (SC) Index for Cotton.

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|
INTERCEPT	106.87424	9.09922	11.75	<.0001
LEPA	-13.72133	12.31137	-1.11	0.2666
FUR	-19.63404	14.90906	-1.32	0.1896
MESA	39.07594	12.58706	3.10	0.0022
SDI	-19.25725	11.55909	-1.67	0.0975
MIN	-0.63667	9.62787	-0.07	0.9474
NT	-35.81298	14.19318	-2.52	0.0125

Table 5.10 presents the parameter estimates for the soil conservation (SC) index per acre of cotton expressed as a function of irrigation system types and tillage systems. The adjusted R^2 for the model is 0.1070. The MESA variable is significant at the 99% confidence level. The NT variable is significant at the 95% confidence level. The SDI variable is significant at the 90% confidence level. MESA and SDI irrigation systems had a soil conservation index value of 39.08 and -19.26 when compared to the base irrigation system LESA, respectively. No-till (NT) systems had a soil conservation index value of -35.81 when compared to the base tillage system, conventional tillage. Given the results, SDI and NT systems are more efficient at conserving soil than the base systems LESA and conventional tillage, respectively. MESA irrigation systems are not as efficient as the

base irrigation system LESA at conserving soil. LEPA and furrow (FUR) irrigation systems are not significantly different from the base system LESA. Minimum tillage (MIN) systems are not significantly different from the base system, conventional tillage.

CHAPTER VI
CONCLUSIONS

<u>Conclusions</u>

One objective of this study was to determine the relationship between the sustainability metrics from the Fieldprint® Calculator and profitability. A production operation must be profitable over the long term in order to be considered sustainable (SARE). This study determined that profitability does not appear to be negatively affected by sustainability. Therefore, the adoption of practices and systems that improve sustainability may sustain or improve profitability. As the sustainability metrics of an operation improve, a producer's profit may increase. However, improving the sustainability of an operation is highly important not only for profit maximization, but also to conserve dwindling resources and meet the world's increased demand for food and fiber.

The first set of models evaluated the effects of the sustainability metrics on profitability as measured by gross margin. For corn, the land use and irrigation water use variables did not have a significant effect on gross margin, but the energy use variable had the expected negative sign and was significant. For cotton operations, the results indicated that the land use, irrigation water use, and energy use variables all had a significant effect on a producer's gross margin and had the expected sign. These results indicate that an improvement in the sustainability metrics (a decrease in the metric index) may have a positive effect on gross margin.

The second set of models evaluated the effects of irrigation and tillage systems on the sustainability metrics. Results from the study indicate that the SDI irrigation system had a negative effect on the land use metric for corn operations in that the land use index was higher with the SDI system. This indicates that corn yields with the SDI system were significantly lower than the base LESA system. This result was not expected and may be a function of limited SDI observations for corn. For cotton production, furrow irrigation systems had a negative effect on the land use, irrigation water use, and energy use metrics compared to the LESA system. The MESA irrigation systems had a negative effect on the land use and soil conservation metrics compared to the LESA system. The SDI irrigation system and no-till (NT) tillage system had a positive effect on the soil conservation metric. It can be concluded that producers using furrow and MESA irrigation systems may improve their sustainability metrics for land use, irrigation water use, energy use, and soil conservation by switching to alternative methods of irrigation including LESA, LEPA, and SDI systems. Producers with specific goals to conserve soil should look into adopting SDI irrigation systems and no-till (NT) systems as they are significantly better at conserving soil than the LESA irrigation system and a conventional tillage system.

The depletion of the Ogallala Aquifer is an important issue facing agricultural producers in the Southern High Plains of Texas, Irrigation management is a major objective of the TAWC project from which the data was obtained for this study. Producers in the study that have adopted LESA, LEPA and SDI irrigation systems have higher irrigation efficiency as measured by the irrigation uses metric compared to furrow and MESA systems. The irrigation use metric can be improved by adoption of more efficient irrigation systems such as SDI; and by more precise crop irrigation management through the use of evapotranspiration measurements and moisture probes. Improving the irrigation use metric not only improves sustainability but also profitability.

The information gained by this study will allow producers to be more informed about their current operational practices as well as new practices they may implement in the future. Additionally, the results from this study will provide producers with more information about how certain production practices influence profit and sustainability metrics. The results from this study will be valuable to producers who have specific production goals such as profit maximization or minimizing their sustainability footprint, as it will allow them to make more informed decisions on how to attain these goals.

Improving agricultural practices will always be necessary due to dwindling resources and to meet the needs of the world's growing population. However, production improvements cannot negatively affect profit or producers will not be able to continue operating. Due to this, sustainable agriculture is key to improving production practices as it takes all aspects of a production operation into consideration when making management decisions including long-term profit, stewardship of natural resources, and the quality of life for farmers, ranchers, and their communities. Tools such as the Fieldprint® Calculator will allow producers to better understand the impact their management decisions have on the environment. By using tools such as the Fieldprint® Calculator, producers can help minimize their sustainability footprint while still maintaining a certain level of profit.

Efforts made to reduce the impact of agricultural productions on the environment is crucial to the continued success of farming in the SHP of Texas. Natural resources such as the Ogallala Aquifer should be conserved. As each producer in the region makes a conscious effort to improve their production practices, the life of natural resources can be sustained for a longer period of time. By conserving resources, producers in the region can continue producing food, fiber, and grain and while reducing the negative impacts of agriculture on the environment.

Further Research

The Fieldprint® Calculator 3.0 will debut in 2016 and will include many beneficial modifications such as allowing producers to enter specific field operations in the tillage section as opposed to a set list of operations which appears currently. It will also allow producers to use tabs within the calculator to simulate change in management practices without affecting data entered into the calculator, such as a transition from a furrow irrigation system to a SDI system. This will allow a producer to see the specific effects of changing production practices and how it effects their sustainability footprint. In addition, the calculator will reveal the specific algorithms and calculations used for each metric in the calculator which will be beneficial for research purposes. The new Fieldprint® Calculator will allow producers and researchers alike to evaluate the effects of specific field operations on sustainability metrics as opposed to an approximation of field operations provided by the calculator.

Further research in the area of sustainable agriculture with an emphasis on the Fieldprint® Calculator could consist of evaluating specific production practices to determine the magnitude of their impact on sustainability metrics. By providing approximate values for each specific field operation performed, more detailed information will be given about production practices, allowing producers to make more informed decisions about their management strategies. Further research could also include the use of the Irrigation Scheduling tool on the TAWC Solutions website. The tool uses information provided by the user to calculate the amount of moisture remaining in the soil based on evapotranspiration rates. This tool could allow a producer to irrigate their crops more timely and efficiently as they would know when to irrigate crops and how much water to apply based on water levels in the soil. By doing so, producers could potentially reduce the amount of irrigation applied, increase profitability due to increased yields and/or lower costs, reduce soil loss, and/or reduce their energy use and greenhouse gas emissions.

REFERENCES

Aillery, M.P., and G. D. Schaible. *Water Conservation in Irrigated Agriculture: Trends and Challenges in the Face of Emerging Demands.* Washington, DC: U.S. Department of Agriculture, Economic Research Service, Economic Information Bulletin No. 99, 2012.

Allen, V.G., C.P. Brown, R. Kellison, E. Segarra, T. Wheeler, P.A. Dotray, J.C. Conkwright, C.J. Green, and V. Acosta-Martinez. "Integrating Cotton and Beef Production to Reduce Water Withdrawal from the Ogallala Aquifer in the Southern High Plains." *Agronomy Journal* 97 (March 2005): 556-567.

Allen, V.G., C.P. Brown, R. Kellison, P. Green, C.J. Zilverberg, P. Johnson, J. Weinheimer, T. Wheeler, E. Segarra, V. Acosta-Martinez, T.M. Zobeck, and J.C. Conkwright. "Integrating Cotton and Beef Production in the Texas Southern High Plains: I. Water Use and Measures of Productivity." *Agronomy Journal* 104 (September 2012): 1625-1642.

Amosson, S. H., L.K. Almas, F. Bretz, D. Gaskins, B. Guerrero, D. Jones, T. Marek, L. New, and N. Simpson. "Water Management Strategies for Reducing Irrigation Demands in Region A." OpenSIUC Conference Proceedings, 2006.

Carlson, G. A., D. Zilberman, and J.A. Miranowski. *Agricultural and Environmental Resource Economics.* New York: Oxford University Press, 1993.

Cobb, C. W., and P. H. Douglas. "A Theory of Production." The American Economic Review. Vol.18 No.1 (March 1928): 139-165.

Duncan, L. A., M.J. Buschermohle, M. Velandia, E. Barnes, and B. Norman. "Fieldprint Calculator: Influence of Management Practices on Cotton Sustainability." Paper presented at the Beltwide Cotton Conference, San Antonio, Texas, January 5-7, 2015.

Earles, R., and P. Williams. Sustainable Agriculture: An Introduction. ATTRA, The National Sustainable Agriculture Information Service, 2005.

Field to Market®: The Keystone Alliance for Sustainable Agriculture – Fieldprint® Calculator. Internet site: https://www.fieldtomarket.org/fieldprint-calculator/

Gramig, B.M., and N.J.O. Widmar. “Estimating Farmers’ Willingness to Change Tillage Practices to Supply Carbon Emissions Offsets.” Paper presented at the 89th Annual Conference of the Agricultural Economics Society, University of Warwick, England, April 13-15, 2014.

Guerrero, B., and S. Amosson. “The Importance of Irrigated Crop Production to the Texas High Plains Economy.” Paper presented at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 3-5, 2013.

Hamilton, H., and E. Reaves. “Food and Beverage Company Sustainable Sourcing Initiatives in Farming Regions.” AGree, September 2014.

Hudson, D. *Agricultural Markets and Prices.* Massachussetts: Blackwell Publishing, 2007.

Johnson, P.N., C. J. Zilverberg, V. G. Allen, J. Weinheimer, P.Brown, R. Kellison, and E. Segarra. “Integrating Cotton and Beef Production in the Texas Southern High Plains: III. An Economic Evaluation.” *Agronomy Journal* 105 (April 2013): 929-937.

Massachusetts Institute of Technology – Mission 2012: Clean Water. Internet site: http://web.mit.edu/12.000/www/m2012/finalwebsite/problem/groundwater.shtml

Mitchell, D., P.N. Johnson, V. Allen, and C. Zilverberg. “Integrating Cotton and Beef Production in the Texas Southern High Plains: A Simulation Approach.” Paper presented at the Southern Agricultural Economics Association (SAEA) Annual Meeting, Orlando, Florida, February 3-5, 2013.

Mitchell, D. “Potential Impacts of Climate Change on Agricultural Production in Uzbekistan.” Ph.D. dissertation, Texas Tech University, December 2014.

O’Connor, C. A. “Soil Matters: How the Federal Crop Insurance Program Should Be Reformed To Encourage Low-Risk Farming Methods with High-Reward Environmental Outcomes.” Paper presented at the Agricultural & Applied Economics Association’s 2013 Crop Insurance and the Farm Bill Symposium, Louisville, Kentucky, October 8-9, 2013.

Osteen, C., J. Gottlieb, and U. Vasavada, (eds.). *Agricultural Resources and Environmental Indicators, 2012 Edition.* Washington, DC: U.S. Department of Agriculture, Economic Research Service, Economic Information Bulletin No. 98, 2012.

Perera, A., S. Putt del Pino, and B. Oliveira. "Aligning Profit and Environmental Sustainability: Stories from Industry." Working paper, World Resources Institute, 2013.

Peterson, J. M., and Y. Ding. "Economic Adjustments to Groundwater Depletion in the High Plains: Do Water-Saving Irrigation Systems Save Water?" *American Journal of Agricultural Economics* 87 (1) (February 2005): 147-159.

Sustainable Agriculture Research and Education (SARE), *What is Sustainable Agriculture?*, 2010, http://www.sare.org/Learning-Center/SARE-Program-Materials/National-Program-Materials/What-is-Sustainable-Agriculture

Texas Alliance for Water Conservation (TAWC), Internet site: http://www.depts.ttu.edu/tawc/

Texas Parks & Wildlife, Map of Panhandle/High Plains District, Internet site: https://tpwd.texas.gov/landwater/land/habitats/high_plains/regulatory/ (Accessed July 1, 2015)

Weinheimer, J., N. Rajan, P. Johnson, and S. Maas. "Carbon Footprint: A New Farm Management Consideration in the Southern High Plains." Paper presented at the Agricultural & Applied Economics Association Conference, Denver, Colorado, July 25-27, 2010.

APPENDIX A.

SUMMARY OF TAWC CORN DATA

This appendix contains a summary of the raw data for TAWC corn from 2007 – 2014. The summary contains the number of observations for each year, irrigation system, and tillage system; the average price received in the Southern High Plains of Texas region for each year; the average yield per year; the average amount of irrigation applied per year; and the average gross margin per year.

Table A.1. Summary of TAWC Corn Data from 2007 – 2014.

Year	Number of Observations	Corn Grain Price ($/bu)	Average Yield (bu)	Average Irrigation Applied (in/ac)	Average Gross Margin ($/ac)
2007	5	$3.69	222.8	13.0	$399.08
2008	10	$5.71	199.5	22.3	$597.65
2009	5	$3.96	231.0	20.5	$443.40
2010	13	$5.64	206.7	12.9	$491.84
2011	4	$5.64	120.8	27.1	$26.62
2012	10	$6.00	141.9	21.2	$280.07
2013	10	$5.00	209.8	21.6	$534.51
2014	10	$5.00	202.7	14.8	$407.42

Table A.2. Number of Observations for Irrigation System Types for Corn.

Irrigation System	Number of Observations
LESA	35
LEPA	11
MESA	5
SDI	16

Table A.3. Number of Observations for Tillage System Types for Corn.

Tillage System	Number of Observations
CON	34
MIN	27
NT	6

APPENDIX B.

SUMMARY OF TAWC COTTON DATA

This appendix contains a summary of the raw data for TAWC cotton from 2007 – 2014. The summary contains the number of observations for each year, irrigation system, and tillage system; the average price received in the Southern High Plains of Texas region for each year; the average yield per year; the average amount of irrigation applied per year; and the average gross margin per year.

Table B.1. Summary of TAWC Cotton Data from 2007 – 2014.

Year	Number of Observations	Price of Cotton Lint ($/lb)	Price of Cotton Seed ($/ton)	Average Yield (lbs/ac)	Average Irrigation Applied (in/ac)	Average Gross Margin ($/ac)
2007	24	$0.58	$155.00	1540.4	11.7	$412.13
2008	17	$0.55	$225.00	1388.6	11.7	$245.49
2009	20	$0.56	$175.00	1259.2	12.2	$222.11
2010	22	$0.80	$150.00	1300.7	8.3	$526.47
2011	26	$0.90	$340.00	1158.9	23.6	$479.71
2012	25	$0.90	$280.00	1248.2	15.0	$657.67
2013	23	$0.80	$260.00	1571.2	16.4	$614.90
2014	24	$0.65	$175.00	1223.9	11.6	$237.55

Table B.2. Number of Observations for Irrigation System Types for Cotton.

Irrigation System	Number of Observations
LESA	47
LEPA	35
FUR	21
MESA	32
SDI	46

Table B.3. Number of Observations for Tillage System Types for Cotton.

Tillage System	Number of Observations
CON	108
MIN	54
NT	19

APPENDIX C.

SUMMARY OF TAWC WHEAT DATA

This appendix contains a summary of the raw data for TAWC wheat from 2007 – 2014. The summary contains the number of observations for each year, irrigation system, and tillage system; the average price received in the Southern High Plains of Texas region for each year; the average yield per year; the average amount of irrigation applied per year; and the average gross margin per year.

Table C.1. Summary of TAWC Wheat Data from 2007 – 2014.

Year	Number of Observations	Wheat Grain Price ($/bu)	Average Yield (bu/ac)	Average Irrigation Applied (in/ac)	Average Gross Margin ($/ac)
2007	4	$4.28	56.4	7.4	$18.28
2008	5	$7.85	69.7	8.9	$254.16
2009	5	$5.30	35.2	6.4	$29.49
2010	4	$3.71	59.4	3.9	$57.73
2011	2	$5.75	51.0	11.3	$12.26
2012	4	$6.85	37.4	4.2	$88.82
2013	4	$6.85	27.6	8.7	-$116.70
2014	1	$6.85	23.8	10.5	-$177.78

Table C.2. Number of Observations for Irrigation System Types for Wheat.

Irrigation System	Number of Observations
LESA	9
LEPA	13
MESA	7

Table C.3. Number of Observations for Tillage System Types for Wheat.

Tillage System	Number of Observations
CON	2
MIN	15
NT	12

APPENDIX D.

SUMMARY OF STATISTICS FOR CORN

This appendix contains a summary of the statistics from the TAWC data for corn from 2007 – 2014. The mean, standard deviation, and range of the unit input per unit output of each metric is included. The mean, standard deviation, and range for each sustainability index is included as well.

Table D.1. Summary of Statistics for TAWC Corn Data (Raw).

Sustainability Metric	Units	Mean	Standard Deviation	Lowest Value	Highest Value
Land Use	(ac/bu)	0.0059	0.0034	0.0036	0.0238
Irrigation Water Use	(in/bu)	0.1118	0.0788	0.0390	0.4798
Energy Use	(gals of diesel/bu)	0.7241	0.4674	0.2835	2.9098
Greenhouse Gas Emissions	(lbs of CO_2/bu)	21.5687	14.1209	8.0476	84.4741
Soil Conservation	(tons erosion/ t-value)	0.5801	0.4370	0.0054	1.3075

Table D.2. Summary of Statistics for TAWC Corn Data (Index).

Sustainability Metric	Units	Mean	Standard Deviation	Lowest Value	Highest Value
Land use	index	100.00	57.3471	60.9760	399.7475
Irrigation water use	index	100.00	70.4719	34.9124	428.9967
Energy use	index	100.00	64.5482	39.1466	401.8326
Greenhouse gas emissions	index	100.00	65.4692	37.3113	391.6510
Soil conservation	index	100.00	75.3374	0.9305	225.3883

APPENDIX E.

SUMMARY OF STATISTICS FOR COTTON

This appendix contains a summary of the statistics from the TAWC data for cotton from 2007 – 2014. The mean, standard deviation, and range of the unit input per unit output of each metric is included. The mean, standard deviation, and range for each sustainability index is included as well.

Table E.1. Summary of Statistics for TAWC Cotton Data (Raw).

Sustainability Metric	Units	Mean	Standard Deviation	Lowest Value	Highest Value
LAND USE	(ac/lb)	0.0007	0.0003	0.0003	0.0022
IRRIGATION WATER USE	(in/lb)	0.0097	0.0064	0.0020	0.0530
ENERGY USE	(gals of diesel/lb)	0.0646	0.0363	0.0263	0.2799
GREENHOUSE GAS EMISSIONS	(lbs of CO_2/lb)	1.7611	1.0543	0.6336	9.1080
SOIL CONSERVATION	(tons erosion/ t-value)	1.6096	0.9315	0.5483	6.2072

Table E.2. Summary of Statistics for TAWC Cotton Data (Index).

Sustainability Metric	Units	Mean	Standard Deviation	Lowest Value	Highest Value
LAND USE	index	100.00	43.1600	47.5641	310.4319
IRRIGATION WATER USE	index	100.00	65.2139	21.4846	538.5860
ENERGY USE	index	100.00	55.5355	40.2779	428.1567
GREENHOUSE GAS EMISSIONS	index	100.00	59.0468	35.4857	514.1606
SOIL CONSERVATION	index	100.00	57.4528	33.5802	380.1748

APPENDIX F.

SUMMARY OF STATISTICS FOR WHEAT

This appendix contains a summary of the statistics from the TAWC data for wheat from 2007 – 2014. The mean, standard deviation, and range of the unit input per unit output of each metric is included. The mean, standard deviation, and range for each sustainability index is included as well.

Table F.1. Summary of Statistics for TAWC Wheat Data (Raw).

Sustainability Metric	Units	Mean	Standard Deviation	Lowest Value	Highest Value
LAND USE	(ac/bu)	0.0273	0.0144	0.010	0.067
IRRIGATION WATER USE	(in/bu)	0.1882	0.1455	0.042	0.622
ENERGY USE	(gals of diesel/bu)	1.2667	0.7893	0.356	3.485
GREENHOUSE GAS EMISSIONS	(lbs of CO_2/bu)	36.3770	22.5904	10.026	96.057
SOIL CONSERVATION	(tons erosion/ t-value)	0.0461	0.0493	0.001	0.215

Table F.2. Summary of Statistics for TAWC Wheat Data (Index).

Sustainability Metric	Units	Mean	Standard Deviation	Lowest Value	Highest Value
LAND USE	index	100.00	52.7518	36.677	244.515
IRRIGATION WATER USE	index	100.00	77.3282	22.233	330.797
ENERGY USE	index	100.00	62.3177	28.087	275.112
GREENHOUSE GAS EMISSIONS	index	100.00	62.1008	27.561	264.059
SOIL CONSERVATION	index	100.00	106.9211	2.168	467.090