ECONOMIC EVALUATION OF SILAGE CROPS UNDER REDUCED IRRIGATION IN THE TEXAS HIGH PLAINS

by

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ABSTRACT

Agriculture production remains a major mainstay of the Texas High Plains economy. However, the primary groundwater source (Ogallala Aquifer) that supports the intensive nature of irrigated agriculture and livestock operations is waning rapidly which raises alarm for future sustainability of agriculture production in the area.

The main goal of the study is to analyze the economic feasibility of corn silage and sorghum silage under reduced irrigation in the Texas High Plains. The specific objectives were to: 1) Estimate water response function for irrigated corn silage and sorghum silage. 2) Use the input response function to determine optimum levels of input to maximize profit for corn silage and sorghum silage production. 3) Perform a comparative analysis of water use between corn silage and sorghum silage and estimate potential water savings. 4) Predict the effect of forage quality of corn silage and sorghum silage on milk yield per ton of forage dry matter.

Data for sorghum silage were obtained from the Texas AgriLife Research Center in Amarillo, Texas from sorghum silage trials 2007 to 2014 whereas corn silage data were obtained from 2009 to 2013 corn silage trials from the State Silage Corn Performance Test at Etter. Models were developed to determine the effect of water on corn silage and sorghum silage yield. These models were further used to determine the optimal input levels of total available water and applied irrigation water to maximize profit. The R^2 value from the restricted model relating corn silage and sorghum silage to

total available water received explained 99% and 97% of the variation in yield, respectively. The profit for irrigated sorghum silage ($43/ton) and irrigated corn silage ($48/ton) in the Northern Texas High Plains are $183/acre and $471/acre, respectively, at a natural gas price of $4/Mcf whereas the Southern Texas High Plains, had $242/acre and $554/acre, respectively, at electricity price of $0.074/kWh.

A total of 258,068 acre-feet of water will be needed to produce 4,180,711 tons of corn silage whereas 239,692 acre-feet of water will be required to grow 4,646,340 tons of sorghum silage to meet the feed (silage) requirement of dairy cows in the Texas High Plains. The amount of water saved if corn silage is replaced by 50% irrigated sorghum silage and 50% dryland sorghum silage is 138,222 acre-feet. Crude protein, *in-vitro* true digestibility, starch, and lignin content of corn silage forage quality explained 99% of the variation in milk yield while sorghum silage forage quality explained 98%. Although there is 16% increase in milk yield in favor of corn silage due to forage quality, it is economically profitable to feed the dairy cows with sorghum silage as far as buying or growing both silages to formulate ration for dairy cows are concerned. The production cost of corn silage in the feed component of dairy cows is 15% more than sorghum silage per year. Improvement in crude protein, *in-vitro* true digestibility, and starch content of sorghum silage will increase the quantity of milk produced per ton of forage dry matter.

Considering global concerns on water scarcity coupled with unpredictable climate changes, it is economically prudent to consider sorghum silage especially in the Texas High Plains where the groundwater (Ogallala Aquifer) is waning.

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CHAPTER I

INTRODUCTION

The economy of the Texas High Plains is made up of a variety of agricultural and non-agricultural industry. The agricultural component embraces a combination of irrigated and dryland crop production together with livestock operations. On the other hand, the non-agricultural sector captures numerous activities such as manufacturing, marketing, and consumer merchandising. Agriculture production remains one of the major driving forces of the Texas High Plains economy and played a dominant role in the livelihood of the people and United States at large (Guerrero and Amosson, 2013).

According to Amosson et al. (2012) the direct value of agriculture in the Texas High Plains exceeded $5.8 billion during 2008-2011, and agribusiness contributed 53,264 jobs with an annual payroll of $1.1 billion in the same period. In 2012, the United States Department of Agriculture (USDA) Census revealed that there are 248,809 farms in Texas with an average farm size of 523 acres; cattle and calves sum up to 11.2 million heads, whereas hog inventory adds up to 800,893 heads. Additionally, the census reports that revenue from agricultural production in Texas in 2012 was approximately $25.4 billion in cash receipts (USDA, Census of Agriculture, 2012). Currently, available inventory for cattle and calves add up to 11.8 million heads whereas that of hogs is 850,000 heads in Texas (USDA/NASS, 2016).

There is no doubt that Texas High Plains is prolific for agricultural production. The favorable long growing season and the topography of the land make the High Plains very congenial for growing a variety of crops as well as the raising of farm animals especially beef, dairy, and swine confined livestock. Obembe et al. (2014) reported that the conducive nature of the High Plains to animal production, especially the climate, environmental benefits, and crop production, had led to increase in dairy cattle population. Milk production levels have risen from 19,646 to 20,898 pounds per head in Texas. The current record from the USDA/NASS (2015) shows that milk production has reached 22,235 pounds per head and total milk production is 10.3 billion pounds in Texas. Economic analysis carried out by Texas A&M AgriLife Extension and Texas Tech University revealed that crop production in the Texas High Plains supported more than 103,000 jobs and generated more than $12.2 billion into the economy of the Texas High Plains in the 2010 economic year (Guerrero and Hudson, 2012).

The major irrigated grain crops grown in the Texas High Plains include corn, grain sorghum, and winter wheat. Besides the aforesaid crops, soybean, cotton, ensilage, and hay are also grown in the High Plains with cotton being the predominant crop. According to the USDA/NASS 2014 State Agriculture Overview, 6,217,000 acres of cotton were planted in Texas. Irrigated corn and sorghum as well as dryland sorghum are also grown in large quantities in Texas High Plains apart from cotton. Table 1 shows corn and sorghum grown for grain and silage, price per unit and value of production in dollars in Texas.

Table 1: Corn and Sorghum Production in Texas, 2014

Commodity	Acreage harvested	Yield/acre	Production (million)	Price/unit	Value (million $)
Corn Grain	1,990,000	148 bu	294.52 bu	$4.45/bu	1,310.61
Corn Silage	210,000	22 tons	4.62 tons	-	-
Sorghum Grain	2,250,000	61 bu	137.25 bu	$7.23/cwt	553.39
Sorghum Silage	100,000	14 tons	1.40 tons	-	-

Source: USDA/NASS, State Agriculture Overview (2014).

The Texas Panhandle is often referred to as the beef capital of the world due to the significant amount of beef the region supplies to the United States and the globe at large. The increasing number of feedlot and dairy farms in the region has called for high demand of feed especially silage to run feedlot and dairy enterprises. Spinhirne (2012) observed that dairy feed rations contain higher amounts of corn silage than concentrate compared to fed beef rations. This accounts for the high demand for corn silage by dairy industries in the Texas High Plains.

Corn silage and sorghum silage play significant role in the sustainability of livestock industries especially the dairy and feedlot. The dairy industry had positively impacted and significantly boosted the economy of the Southern Ogallala Region and the entire Texas High Plains. The total economic impact of dairy industry in the Texas High Plains has been estimated to be more than $ 2.7 billion (Guerrero et al., 2012; Almas et al., 2015). The labor intensive nature of the business, which needs 30-37 employees per 3,000 head of dairy cows, has increased jobs in Texas (Guerrero et al., 2012). A greater percentage of the ration used to feed the animals in the dairy industry comes from corn silage and sorghum silage in the Texas High Plains.

A critical look at the price per ton of corn silage to sorghum silage over the years from the Texas Crop and Livestock Enterprise Budgets shows that the former is more expensive than the latter; however, most dairies prefer corn silage to sorghum silage. According to Almas et al. (2015) the 2012 Texas Crop and Livestock Budget showed that the price of corn silage was $53.47 per ton whereas sorghum silage was $48.12 per ton. Even though there have been complaints of large feed yards paying the same price for corn silage and sorghum silage in the Texas Panhandle (Obembe et al., 2014). The demand for sorghum silage becomes significant during drought conditions or summers where there is inadequate amount of water for production.

Sorghum is able to withstand drought more than corn. Studies have shown that sorghum silage requires less water than corn silage. In order to dry down to the proper moisture level for ensiling, water requirement for sorghum silage has to be stopped several days to two weeks prior to harvest. At this stage the moisture content will be between 65 to 70% hence, most farmers switch from corn silage to sorghum silage as the best alternative to minimize irrigation cost and maximize profit during drought conditions (Obembe et al., 2014; Almas et al., 2015). Livestock farmers usually face the challenge of getting adequate feed to run their enterprise especially in areas where whole year grazing is not accessible. Hay and alfalfa are usually expensive during drought conditions because yield is low and demand is high (Rasby, 2011). The situation also increases the demand for silage by most livestock producers to feed their animals in order to remain profitable in the business.

Although there are cases of inadequate feed especially in places where whole year grazing is inaccessible, corn silage acreages have doubled in Texas from 70,000 acres in

1995 to 160,000 acres in 2006, and a majority of these increases are found in the High Plains (Wenwei et al., 2007). Seven out of ten top milk producing counties in Texas are now located in the Texas High Plains due to availability of feed for animals. In 2007 a cheese plant was established in Dalhart by Hilmar Cheese Company; the facility is capable of processing about 5 million pounds of milk per day. This has led to high demand for silages in the region (Wenwei et al., 2007).

One major problem facing the Texas High Plains is the declining rate of the Ogallala Aquifer. Agriculture production in the High Plains depends largely on the Ogallala Aquifer for survival. The amount of precipitation received in the High Plains is inadequate to support the intensive nature of agricultural activities; therefore the aquifer serves as the lifeline to crop and animal production. The aquifer extends from the Dakotas to the Southern Plains of Texas and makes up approximately 174,000 square miles. It averages 200 feet of saturated thickness, ranging from less than 1 foot to 1,300 feet, depending on the location (Guerrero et al., 2013). Besides the high demand of water from the Ogallala for agricultural production, it also serves as a source of water for municipal and industrial use. The aquifer system provides drinking water to 82% of the people who live within its boundaries and yields about 30% of the nation's groundwater used for irrigation (USDA/NRCS, Ogallala Aquifer Initiative 2011 Report, 2012).

The high demand of water from the aquifer for irrigated agriculture has become a greater concern since withdrawal is more than the recharge rate. Several studies have been conducted on the various ways to sustain the aquifer's life for continual usage especially for food production and other agricultural related activities. For instance, Jeffrey et al. (2003) found that among the policies laid down to check efficiency, equity, and moral motives of sustaining this cherished water resource in the High Plains, only economic efficiency has largely driven the shaping of the water policies in the Texas High Plains. The North Plains Groundwater Conservation District, in partnership with the Texas Alliance for Water Conservation and Texas Tech University, recently received a $499,848.00 Conservation Innovation Grant from NRCS for the Texas High Plains Initiative for Strategic and Innovative Irrigation. The partnerships' primary objective was to quantify water savings that would be realized from strategic irrigation management and will ultimately contribute to the area's economic sustainability as well as prolonging the life of the aquifer (UDSA/NRCS, 2012).

The expanding nature of dairy and feedlot industries in the Texas High Plains put pressure on the already declining aquifer. The silages require a greater quantity of water to produce a desirable yield especially corn silage and corn grain. Studies have been conducted on the yield and nutritional value of irrigated sorghum silage varieties and the possibility of replacing corn silage with sorghum silage as an alternative feed for livestock industries. For instance, extension specialists investigated water use, quality, digestibility, nutritional, and feed conversion features of forage sorghum silage varieties. Results revealed that sorghum silage can be an attractive alternative crop for feedlot and dairy industries because it is able to supply almost equal nutritional value as corn silage and requires about one-third less water than corn silage (Dean et al., 2007). The less water usage or drought tolerant nature of forage sorghum silage is an advantage to reduce the quantity of water used for production in the Texas High plains. Almas et al. (2015) reported that the decision to switch 30,000 acres from irrigated corn silage, irrigated grain sorghum, and dryland grain sorghum to irrigated sorghum silage will lead to economic benefit amounting to $4.904 million as well as saving 116,373 acre-feet of water.

Research Objectives

The general objective of the study is to evaluate the economic feasibility of silage crops under reduced irrigation in the Texas High Plains. The specific objectives were to:

1. Estimate water response function for irrigated corn silage and sorghum silage.
2. Use the input response function to determine the optimum levels of input to maximize profit for corn silage and sorghum silage.
3. Perform a comparative analysis of water use between corn silage and sorghum silage and estimate potential water saving.
4. Predict the effect of forage quality of corn silage and sorghum silage on milk yield per ton of forage dry matter.

CHAPTER II

LITERATURE REVIEW

Corn Silage and Sorghum Silage Production

The growing numbers of dairy and beef industries in the Texas High Plains require large amounts of high quality silage to run the business. Corn silage has been the dominant feed for most feedlot and dairy industries in the High Plains. Wenwei et al. (2011) reported that a total of 2.3 million acres of corn were planted in 2010 in Texas for both grain and silage where 140,000 acres were harvested for silage with an average silage yield of 18.0 tons per acre. Also a total of 54, 227 irrigated acres of corn silage were harvested in the Northern High Plains while the Southern High Plains harvested 10,142 acres in 2012. In the same year, a total production of 2,445,089 tons of corn silage were recorded in the Northern High Plains whereas the Southern High Plain had 240,765 tons (USDA, Census of Agriculture, 2012).

Although, research in the High Plains has shown comparable yields with less water and yield advantages in limited input systems (Bean and McCollum, 2006; Howell et al., 2008; Marsalis et al., 2009, 2010), sorghum silage acceptance has been low and corn silage continues to be the dominant crop grown. Efforts to increase sorghum silage use in dairies have been met with some resistance however, in some areas, producers are beginning to see the yield potential. But up to this point, corn silage still gets the nod if irrigation is available (Bean and McCollum, 2006).

The potential for forage sorghum as a substitute to corn silage has taken center stage in the research world of the dairy and beef industries, especially in the Texas Panhandle. Most studies recommend sorghum silage as a viable alternative to corn silage because the crop has the potential of saving up to 50% irrigation water in production. Recent developments have shown that a lot of feedyards are considering switching from corn silage to forage sorghum silage due to the potentiality of providing equal value to corn in milk and cattle gain as well as using less water for production (McCollum and Bean, 2007).

Irrigation water has been heavily utilized to produce dairy forages for the ever growing dairy and feedlot industries in the High Plains due to the region’s semi-arid climatic nature. The declining water availability has increased interest in sorghum silage to replace some or all corn silage due to its ability to withstand drought. One major problem usually faced by silage producers is the ability to select varieties with high tonnage potential and acceptable qualities (Wenwei et al., 2013). Hybrid selection influences management decision in silage production because the correct hybrid can often mean the difference between breaking even and making a profit.

Corn silage requires 22.5 inches of irrigation water per acre whereas sorghum silage needs 16 inches of irrigation water per acre (Stichler and Fipps, 2003). Corn silage yield is between 27 to 32 tons/acre on average while sorghum silage yield is at 20 to 26 tons/acre on average. According to Stroup and Miller (2004) forage sorghums can be grown in a wide variety of soil types with pH levels of 5.5 to 8.5 and varying moisture levels. Sorghum has unique characteristics, for instance, the crop’s ability to use less water compared to corn for silage production provides considerable flexibility for forage/livestock producers to manage their resources and respond to critical needs of their livestock. Forage sorghum uses approximately 40-50% less water compared to corn to produce the same dry matter (Stroup and Miller, 2004).

McCorkle et al. (2007) found that, if 54,000 acres of irrigated corn silage in the Panhandle are replaced by sorghum silage, the amount of water saved would be around 400,000 acre inches. The benefit of this move will lower the cost of pumping irrigation water by $2.8 million annually at a natural gas price of $7/Mcf. In 2014 the Texas Crop and Livestock Enterprise Budgets estimated the return above specified cost per acre of Bt sprinkler irrigated corn silage production in the Panhandle to be $78.92 at a yield of 27 tons/acre, whereas sorghum silage was $34.54 at 21 tons/acre. The estimate for 2015 showed a deficit of $7.39 return per acre for corn silage at a yield of 27 tons/acre while, sorghum silage had $65.54 at 21tons/acre. Although yield from both crops are not the same, the cost incur per unit of irrigation (energy cost and irrigation labor) differ significantly. The 2015 estimate showed that energy and irrigation labor cost for sorghum silage will be $65.68 to produce 21 tons/acre whereas, that of corn silage will be $101.04 to produce 27 tons/acre. The deficit of $7.39 for corn silage gives an indication that more of corn silage has to be produced in order to break-even and make profit. However, this will call for more use of irrigation water leading to increase in cost of production unlike sorghum silage.

The annual crop production summary report of USDA-NASS (2012) revealed that sorghum silage production increased from 400,000 tons in 2011 to 2,080,000 tons in 2012. The percent increase in sorghum silage production was 420 in a year. This shows a remarkable progress in sorghum silage production although corn silage continues to take the lead in the quantity of silage produce in Texas. Figure 1 and 2 show the annual total production of corn silage and sorghum silage as well as yield (tons) per acre in Texas.

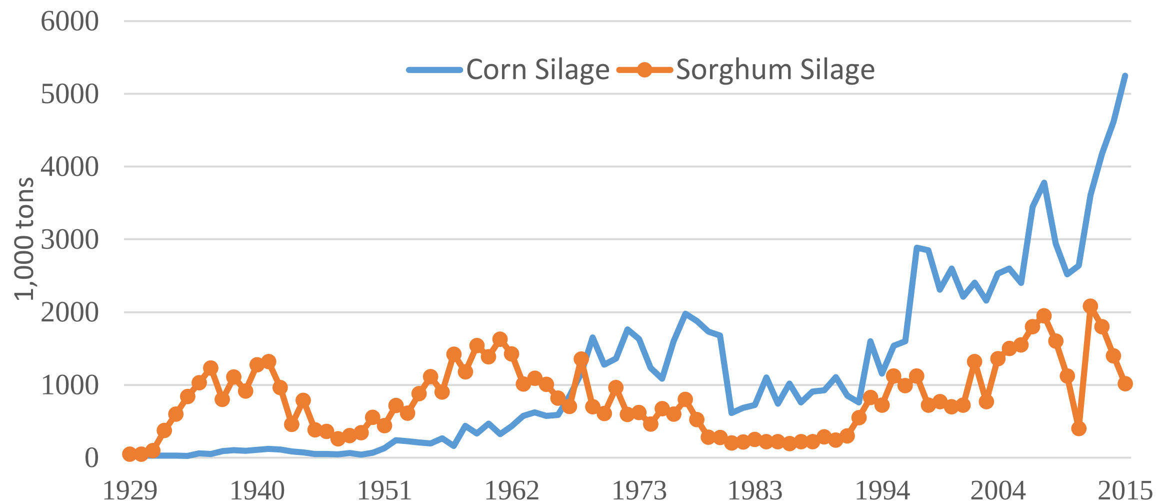

Figure 1. Annual Corn Silage and Sorghum Silage Production in Texas (1929- 2015). Source: (USDA/NASS)

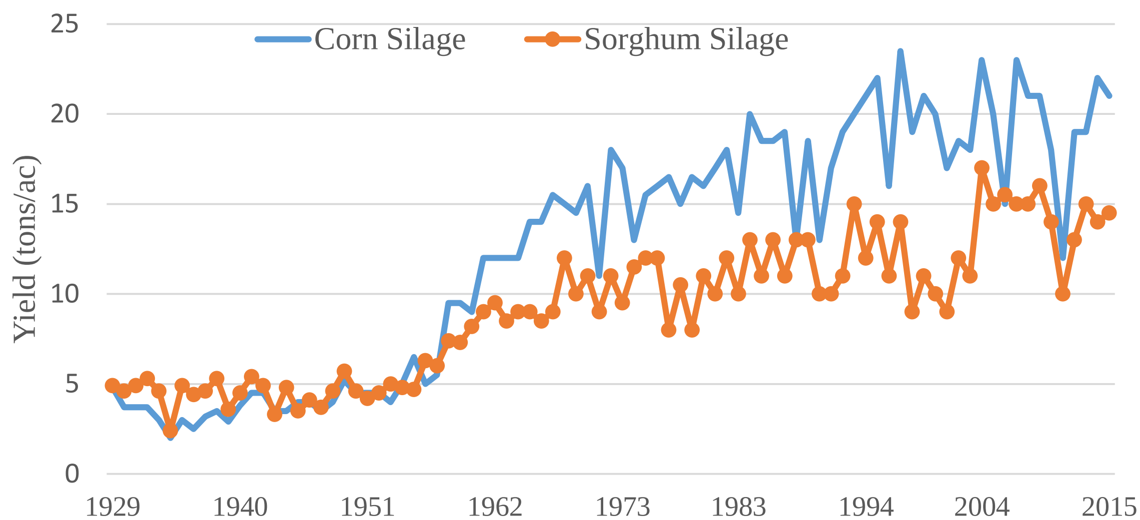

Figure 2. Annual Corn Silage and Sorghum Silage Yield in Texas (1929- 2015). Source: (USDA/NASS)

Irrigated Agriculture in the Texas High Plains

Texas High Plains is known to have semi-arid vegetation, and receives annual growing season precipitation of between 8 to 12 inches. This amount of rainfall is inadequate to support the intensive nature of crop production in the High Plains (Weinheimer et al., 2013). Scarcity of water and unpredictable weather conditions, especially drought, severe heat, and frost had led to multi-billion dollar losses to agricultural production on several occasions in the High Plains and United States as a whole (Smith and Katz, 2013).

Several researchers have studied the transition of irrigated to dryland acreage in the Texas Panhandle with respect to economic feasibility. For instance, Yates et al. (2010) found that annual net loss of over $1.6 billion of gross output and over $616 million of value added as well as 7,300 jobs would be incurred as loss to the economy of the Texas High Plains if irrigated acres are converted to non-irrigated dryland farming. Guerrero and Amosson (2013) also reported that irrigated agriculture contributes $6.6 billion in industry output and $2.1 billion in value added to the High Plains economy, while supporting 58,900 jobs in the region. Switching from irrigated agriculture to complete dryland production will result in economic decline of $4.3 billion in industry output and $1.4 billion in value added. This will also affect more than 34,600 jobs (Guerrero and Amosson, 2013). The impact of the loss to the economy of the High Plains will be unbearable if such a decision is tolerated without having a second look. Irrigated agriculture is therefore needed to help crop production in order to sustain the livelihood of the inhabitants in this great region and United States at large.

Irrigation management is a complex process involving commitment of substantial time, capital, labor, equipment, and water. Often, availability of one of these resources during the cropping season can mean the difference between profit and loss. In the Texas High Plains, drought and reduced water resources has led to inadequate water supplies to satisfy crop moisture needs during part, or all, of the irrigation season (Colette et al., 2008).The significance of irrigation to agricultural productivity as far as yield is concerned cannot be overestimated. Howell (2001) asserts that irrigation plays essential role in the crop production system of the Texas High Plains, and that it is able to quadruple crop yield compared to dryland farming. Ahamadou et al. (2012) also observed that irrigation increases yield by 2 to 7 times compared to non-irrigation and cut down risk by 75% to 90% when risk is defined as a function of the variability in yield. Jordan et al. (2012) reported that the dairy industry in 4 of the top 10 dairy states in the nation (CA, ID, NM, and TX) rely on irrigation to grow the forage crops consumed in the rations fed to their cows.

The pumping of underground water for irrigation in the Texas High Plains started in the early 1911 through to 1940s when internal combustion engines, turbine pumps, right-angle gear drives, and rotary well drilling machines were available. The amount of irrigation water pumped from the underground water increased in the early 1950 to 1974 (Musick et al., 1988). Today, technology and improved irrigation facilities have led to an increase in the number of irrigated acreage by farmers in the Texas High Plains. The primary provider of groundwater for irrigated agriculture in the Texas High Plains is the Ogallala Aquifer. Although the Ogallala Aquifer plays important role in irrigated agriculture in the Texas High Plains, the rate of water withdrawal from the aquifer to recharge is alarming (Almas et al., 2007). The amount of irrigation water taken from the Ogallala Aquifer has gone up to the extent that it calls for urgent water conservation strategies in order to maintain the significant services it offers to the people of the Texas High Plains and future generations (Tewari et al., 2011).

Research has shown that the Panhandle is one of the greatest water consuming regions in the state, using 90% of water for agricultural purposes and that irrigated agriculture consumes more than 10 million acre-feet of water annually in the region (Almas et al., 2010). Sangtaek et al. (2006) noted that the most commonly used irrigation systems in the Texas High Plains for crop production are the ancient furrow irrigation and low pressure sprinkler systems. However, Wallander (2015) asserts that under this traditional gravity-fed irrigation technology, a significant portion of applied water usually gets lost through evaporation, run-off, and infiltration below the root zone. Through research and technology more efficient irrigation systems with low energy precision application (LEPA) has been developed. The pressure-fed and micro irrigation systems are known to deliver irrigation at a pace where water losses are much lower and allow irrigators to maintain higher yields with lower application rates (Wallander, 2015).

The Subsurface Drip Irrigation (SDI) system has been given attention by producers due to its high water use efficiency. Colaizzi et al. (2006) reported that SDI system enhances crop yield under very limited irrigation relative to sprinkler methods for a variety of crops and locations. Other irrigation systems (Variable Rate Irrigation) that prove to be technically viable have also been developed and tested, but their economic feasibility makes farmers hesitant to adopt due to high initial investment cost (Sangtaek et al., 2006).

With the current increase in the cost of pumping water and other initial investments for crop production, there is need for producers to adopt irrigation technology and production practices which maximize profit and minimize cost. Harry (1988) found low pressure irrigation sprinklers, low energy precision application (LEPA) system, improved surface systems including surge flow, alternate row irrigation, precision land leveling, automated gated pipe, and tail water recovery systems as good water saving irrigation technologies. Almas et al. (2010) also reported conventional furrow (CF), surge flow (SF), mid-elevation sprinkler application (MESA), low elevation spray application (LESA), low energy precision application (LEPA) and subsurface drip irrigation (DRIP) as the most commonly used irrigation systems in the Texas High Plans due to their ability of enhancing water use efficiency.

The SDI system involves the application of water below the soil surface through emitters with discharge rates generally in the same range as drip irrigation. It has high application uniformity, no surface run-off, and negligible deep percolation of water accompanied with high yielding and low water use, hence suitable alternative to other irrigation systems in semi-arid regions where there is limited annual precipitation (Romero et al., 2005). Although the above mentioned irrigation systems used in the Texas High Plains are deemed to save water and promote water use efficiency, their investment cost has to be considered since businesses aim to maximize profit and minimize cost. The irrigation expense alone for an average 54 Mg ha^{-1} crop grown under a 120 acre center pivot in the Texas Panhandle is estimated to cost $789 per ha (Amosson et al., 2011).

Crop Water Productivity

Water is an important and often scarce resource which is the key for the sustainability of agriculture, especially in arid and semi-arid regions where precipitation is relatively low (Blair and Kulbhushan, 2014). Accurate estimations of crop water requirements are important to enhance optimization and efficiency of applied water to maximize productivity. Improving agricultural water productivity is a critical response to the growing water scarcity, including the need to reserve ample water in river bodies and aquifers to sustain the ecosystem as well as meeting the growing demands of cities and industries.

Crop water productivity is defined as the ratio of crop yield or crop value to a selected measure of water consumed, applied or evaporated in the process of growing a crop (Wichelns, 2014). The ratio represents the average productivity of the input, but not the incremental productivity. For instance, when the ratio of interest is the water productivity of applied water, the ratio is expressed as: WP_{AW} = Crop Yield (tons/ac)/Applied Water (acre-inches) where, WP is the water productivity and AW is the applied water. Assuming the crop yield is 20 tons per acre and the water applied is 13 inches per acre, the crop water productivity will be 1.54 tons per inch. Neglecting all other inputs that will affect the yield of a crop, this measurement of average productivity is not enough to determine whether the application rate of 13 inches of water per acre is optimal from the farm level perspective. The question of optimality is addressed only by considering the marginal productivity of water in relation to its marginal cost. If the marginal productivity of water is 0.005 tons per inch and the price of the crop is $1,000 per tons, then the decision to apply the last inch of water is plausible provided the marginal cost of water is less than or equal to $5.00 per inch.

Economists usually used crop water production function to explain the technical relationship between yield and amount of water used. The approach also helps to determine how varying amount of water influence crop yields (Liu et al., 2002) as well as the marginal or incremental effect of the productivity of water applied. The average and marginal productivities of water can be illustrated in the context of a crop water production function. Several studies have been conducted using crop water production models to determine the profit maximizing amount of water to be applied and its productivity. For instance, Igbadun et al. (2012) conducted a study on onion production and used a crop water production model in which the onion bulbs yield was expressed as a function of seasonal applied water: Yield (tons/ha) = $-14.88 + 0.131AW - 0.0001AW^2$ where, AW is the applied water. The applied water variable was measured in mm.

Based on this empirical production model, water productivity could be maximized by farmers when they apply 400 mm (15.75 inches) of irrigation water. The yield of onion bulbs would be 21.25 tons per ha and the water productivity would be 0.053 tons per mm of water applied. From this model farmers could still obtain the maximum yield of 28 tons per ha by applying 655 mm of irrigation water. However, the crop water productivity will decline to 0.043 tons per mm at maximum yield but the famers would be producing an additional 6.75 tons of onion bulb per ha. Since we do not have cost function, it will not be possible to determine the profit maximizing quantity of applied water. The profit maximizing quantity of water to apply is found where marginal value product is equal to marginal factor cost. This is determined by transforming the crop water production function into a crop revenue function by multiplying crop price. The shape of the crop revenue function will be the same as the crop water production function.

It can be assumed that if onion production is profitable, then the optimal quantity of applied water will be between 400 mm where crop water productivity is maximum, and 655 mm where yield is maximum and the marginal productivity of water is zero. Zhang and Oweis (1999) also examined durum wheat production in Syria, where farmers depend partly on precipitation and partly on supplemental irrigation water. The estimated crop water model used for the study was: Yield (tons/ha) = -5.8556 + 0.0329 (AW+P) – 0.00002164 $(AW+P)^2$ where, the supplemental irrigation (AW) and the precipitation (P) were expressed in mm. Figure 3 is an illustration of crop yield as a function of applied water.

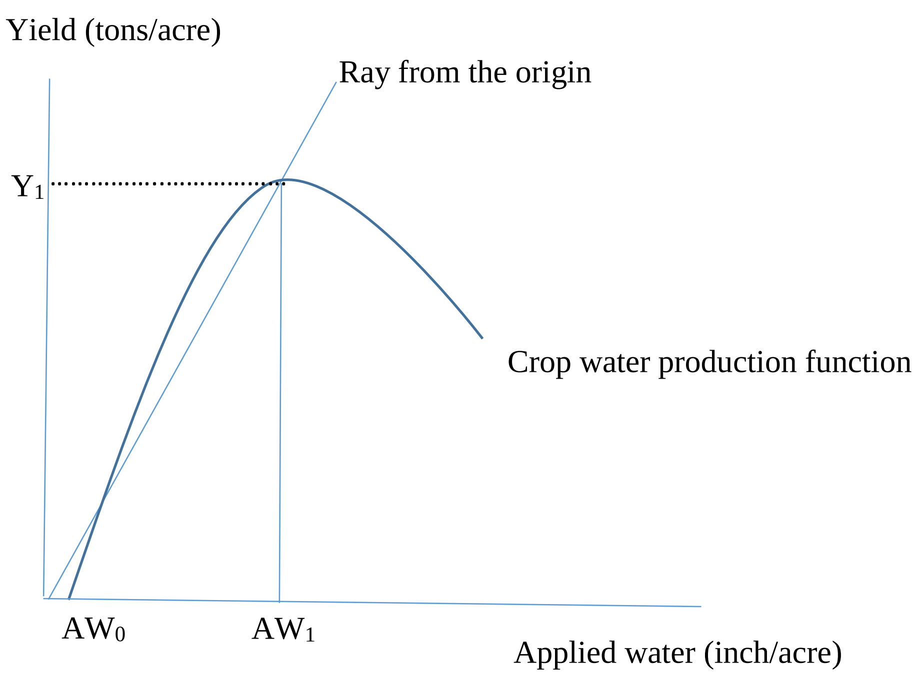

Figure 3. Crop Water Production Function.

Water Use Efficiency of Corn Silage and Sorghum Silage

Irrigation scientists and engineers have used the term "Water Use Efficiency" to describe how effectively water is delivered to the crop and to indicate the amount of water wasted at the plot or farm level. Water use efficiency is defined as the ratio of irrigation water transpired by the crops of an irrigated farm during their growth period to the water diverted from a river or other sources into the farm during the same period of time (Israelsen, 1932). This definition was further improved by introducing the concepts of uniformity, adequacy, and sagacity of irrigation (Solomon, 1984; Wittlesey et al., 1986; and Solomon and Burt, 1997). Turhollow et al. (2010) also defined Water use efficiency (WUE) as a measure of yield per unit of water consumed which varies with site conditions.

In the Texas High Plains, 40% of the cropland uses irrigation for crop production (Almas et al., 2015). Corn has been identified as one of the highly susceptible crops to water stress. Wenwei et al. (2007) found that 2 million acreages of corn are planted annually in Texas, and about 60% of corn grain is produced in the High Plains. Colaizzi et al. (2009) reported that corn uses about 41% of the overall water pumped for irrigated agriculture from the Ogallala Aquifer in the Texas High Plains.

Investment in irrigation for corn production either for grain or silage in the Texas High Plains is relatively expensive in terms of irrigation equipment, fuel, maintenance, and labor. Singh (1991) observed that corn needs about 23.6 inches of water during its entire lifecycle. The rate of irrigation and timing is very crucial on yield and operating cost. Derrel et al. (2010) found that the cost to pump an acre inch of irrigation water depends on: the amount of work that can be expected from a unit of energy, the distance water is lifted from the groundwater aquifer or surface water, the discharge pressure at the pump, the efficiency of the pumping plant, and the cost of a unit of energy. Lee (2013) reported that in order to efficiently use water and optimize production, it is appropriate to look at the soil water conditions throughout the root zone of the crop being grown. Howell et al. (1995) found water use efficiency (WUE) for fully irrigated corn to range from 1.27 to 1.35 kg m^{-3}. Spinhirne (2012) observed that an increase in irrigation water beyond 75% of crop evapotranspiration or increased plant density in excess of 30,000 plants per acre do not favor corn silage yield.

Wenwei and Marek (2014) conducted a study to determine the water use efficiency, length of maturity, and level of irrigation of the brown midrib or the BMR trait of corn silage. Two BMR and four non-BMR corn hybrids with maturity of 100-110 days were grown under four different irrigation treatments in the Northern Panhandle. Results revealed that there was no significant change in irrigating at 100 percent of evapotranspiration (ET), in term of yield or quality over 75 percent ET. However, yield and quality began declining below irrigation levels of 75 percent ET. Also, the BMR did not do better than the non BMR under drought conditions. However, some differences existed between hybrids per parameter, and overall digestibility was similar for BMR and non BMR hybrids. The study concluded that quality is such an important part of silage, because a half inch short in irrigation water severely affects the quality of silage. In the same manner, Montgomery (2009) reported that silage produced under 50% reduction in irrigation affects many yield and quality factors.

Bean and Marsalis (2012) also acknowledged that to get quality corn silage, the water need of the crop should be equivalent to corn grown for grain. They further stressed that corn silage that is dependent on rainfall will need about 26 inches annual rainfall, whereas, for irrigated corn silage, the water requirement should be similar to that needed for grain production. The daily peak water demand for corn in Texas Panhandle was found to exceed 0.4-0.5 inch/day. Therefore, a minimum well capacity of 5.0-6.0 GPM/ac was recommended to help meet the demand (Bean and Marsalis, 2012).

Forage sorghum silage on the other hand has been identified to use less water compared to corn silage. Crop research specialists at the Texas AgriLife Extension observed that forage sorghum silage varieties use about one-third less water compared to corn (Wenwei et al., 2011). Brouk and Bean (2012) found that forage sorghum silage yields have been similar to those of corn while using 30% less irrigation water. In trials conducted in 2003 and 2004, sorghum silage yield increased approximately 0.75 tons per acre (at 65 percent moisture) for every inch of water used by the crop. Marsalis (2011) suggested that forage sorghum can be a viable option to corn in silage systems experiencing water reduction and where long dry periods affect the ability of marginal irrigation systems to meet the water demand of corn.

The low demand of irrigation water for sorghum silage production has led to the expansion of acreages allocated to its production in the Texas High Plains. The best alternative crop to corn for silage production in the Panhandle region of Texas where availability of irrigation water is becoming a bigger issue is sorghum. In field trials over the period of 2001 to 2003, comparing sorghum silage to corn silage, yields ranged from 19.2 to 26.9 tons per acre for sorghum silage while corn silage yield was 23.8 to 25.5 tons per acre (McCorkle et al., 2007). Studies have shown that forage sorghums have the potential to produce as much, and in some cases more, dry matter than corn when grown with the same amount of water (Anderson and Guyer, 1986; Teutsch, 2002). Sorghums have a lower transpiration ratio than corn and require less water per unit of dry matter produced (Martin, Leonard, and Stamp, 1976).

Corn Silage and Sorghum Silage Impact on Milk Production

The dairy industry in the Texas High Plains has seen a progressive growth over the recent years. The number of dairy cattle especially in the Northern and Southern High Plains are on the rise. For instance, Gaus et al. (2011) reported that the number of dairy cattle in the Northern High Plains has risen from 6,000 head in 2000 to more than 185,000 head in 2010. In the same vain, the Southern High Plains had 10,800 head of dairy cows in 2000 and 49,000 in 2010.

Additionally, milk production has also risen from 1.79 to 385.5 million pounds from 2000 to 2009 in the Northern High Plains while the Southern High Plains recorded an increase from 2.1 to 115.4 million pounds in the same year period. Records from USDA/NASS (2014) show that Texas made a total sale of 2.5 billion dollars of milk produced in 2014. Milk production in pounds per head of animal was also found to be 22,268 in the same period. In 2014, the inventory of dairy cows in Texas was 470,000 head of which 226,000 were found in the Texas High Plains (USDA/NASS, 2014). Figure 4 and 5 show total milk production by the dairy industry in Texas.

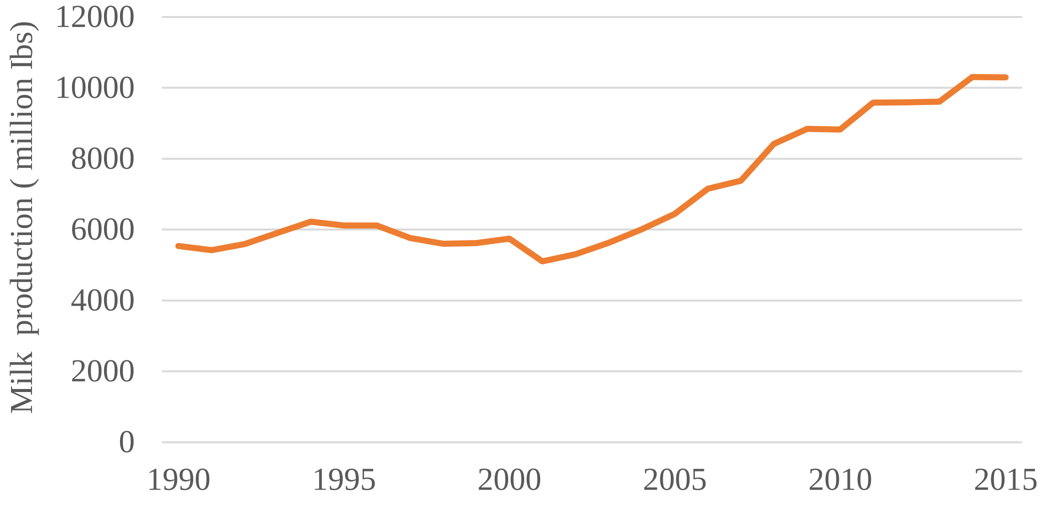

Figure 4. Annual Milk Production in Texas from 1990- 2015.
Source: USDA/NASS

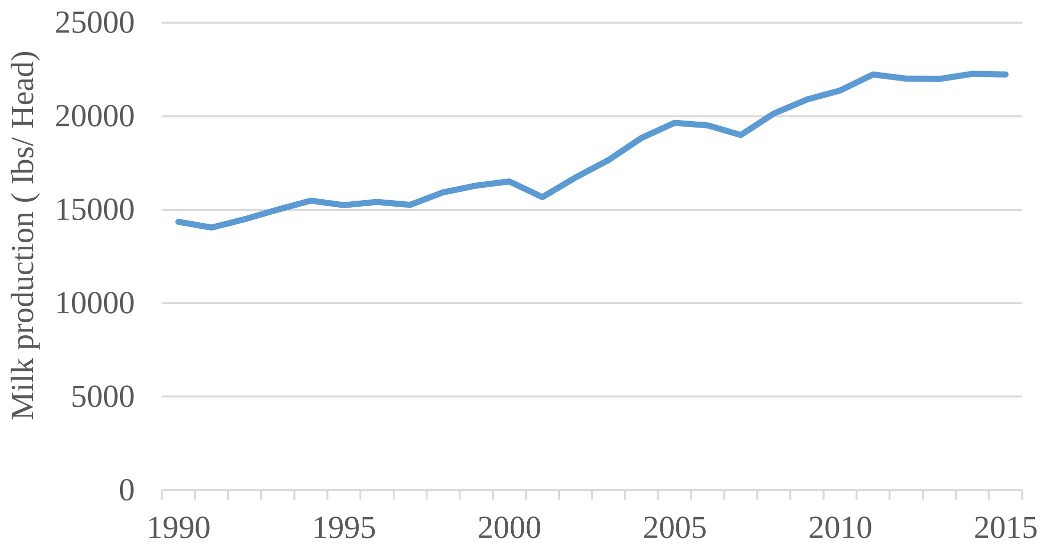

Figure 5. Texas Milk Production from 1990-2015.
Source: USDA/NASS

Silage is one of the key components for dairy ration. The average lactating dairy cow needs approximately 90 pounds of feed per day. This feed must possess adequate protein and be easily digestible, relatively inexpensive and readily available. Corn silage has been the dominant feed component of dairy animals' diet in the High Plains, although sorghum silage is catching up. Corn silage enhances quality milk production due to high digestibility, ease of handling, and palatability. However, Jordan (2015) found no significant difference in dry matter intake, milk yield or milk composition of corn silage and sorghum silage fed to 48 mid-lactation cows. The study recommended the use of large number of animals to further confirm the results.

The BMR sorghum silage has higher digestibility and able to produce milk in a manner similar to corn silage when fed to dairy cows. Oliver et al. (2004) compared brown midrib-6 and -18 forage sorghum with conventional sorghum and corn silage in diets of lactating dairy cows. The results revealed that cows fed the bmr-6 sorghum and corn silage had similar milk production. Cows fed conventional sorghum had the lowest milk production, and cows fed the bmr-18 did not show differences in milk production from cows fed the other diets.

The metabolisable energy (ME) available to the animal for heat and maintenance greatly influence the amount of milk produced by the animal. Hristov et al. (2005) found that metabolisable energy (ME) and protein intake together with other nutrients such as fat and carbohydrates influence milk yield and composition. Therefore, an ideal ration formulation system should include: 1) an intake model that takes independently in account both dietary and animal characteristics, 2) feeding level and associative effects on the true nutrient supply, and 3) accurately predicts production responses to the changes in nutrient supply (Hristov et al., 2005).

Hulme et al. (1986) reported that accurate prediction of the marginal production responses to the changes in nutrient supply is more important than predicting actual production levels. This will help to optimize the margin over feed costs within a herd.

Studies have been done to model the responses of dairy cows to the changes in metabolisable energy intake derived from the forage to concentrate ratio. One of such studies found that dairy cows show diminishing returns in milk and milk energy output with increasing nutrient supply however, limitations to these kinds of studies are that the models do not take into account other nutrients such as diet composition (Hulme et al., 1986; Woods et al., 2003, 2004) According to Cabrita et al. (2009) milk yield increase in dairy cows that results from their genetic improvement requires the use of large amounts of concentrates that are rich in energy and crude protein (CP) to meet their nutrients requirements.

Weiss and Wyatt (2006) found that milk production for cows fed with BMR was higher than for cows fed with corn silage dual-purpose hybrid (81.4 vs. 77.8 pounds/day). However, because of changes in fat concentration, yield of energy-corrected milk was not affected by treatment. The only interaction observed was increased yield of milk protein when BMR silage was combined with increased supply of metabolisable protein (Weiss and Wyatt, 2006). Educating livestock producers and other professionals on the true value of sorghum to the dairy industry will go a long way to reduce silage production cost especially with corn silage and save more water for future generation (Brouk and Bean, 2012).

Nutritional Qualities of Corn Silage and Sorghum Silage

Corn and sorghum silage play significant role in the diet of animals in the dairy and feedlot industries. They are often used to supplement both growing and finishing ration. In terms of nutritional and silage quality, corn silage outweigh sorghum silage in feed value. However, some sorghum hybrids have been found to have similar nutritional value to corn (Bean and Marsalis, 2012). Many studies have compared the nutritional value of sorghum silage and corn silage and concluded that the brown midrib (BMR) and some non-BMR varieties of sorghum have qualities similar to corn in term of digestibility (Bean and McCollum, 2006). Rick (1994) reported that forage sorghum silage has 80 to 90% of the energy value of corn silage per unit of dry matter. Brouk and Bean (2012) found *in-vitro* true digestibility (IVTD) for pre-ensiled corn silage to be between 81-83% whereas average value for the normal and BMR types of forage sorghums also had 76% and 81%, respectively.

Dann et al. (2008) did a study that compared brown midrib sorghum-Sudan (bmrSS) grass with corn silage (CS) on lactation performance and nutrient digestibility in Holstein dairy cows. The results revealed that cows fed with bmrSS had greater efficiency of solids-corrected milk production, higher ruminal pH, and greater acetate to propionate ratios than cows fed corn silage. It was concluded that in a short-term study, bmrSS appears to be an effective alternative to the corn silage hybrid when fed at either 35 or 45% of dietary dry matter.

The nutritional value and quality of silage are influenced by biological and technological factors. Some of these factors include the crop species, stage of maturity and dry matter (DM) content at harvest, chop length, forage density after packing, sealing technique, feedout rate, weather conditions at harvest and feedout, additive use, timeliness of the silage-making activities, and the training of personnel. For instance, the chop length of silage for dairy cattle should be 3/8 to 1/2-inch. A finer chop will cause dairy cows to develop abomasal displacements, low milk fat test, and off-feed problems (Rick, 1994). Guyer (1986) reported that corn silage is a medium energy feed that is similar to 50% grain and 50% hay ration and contains 7.5 to 9% crude protein in dry matter basis. Neal et al. (2008) also found neutral detergent fibre (NDF) content, neutral detergent fibre digestibility (NDFD), starch content, and starch digestion are major factors that determine nutritional value of corn silage for dairy cattle.

Bean et al. (2003) compared different types of forage sorghum silage for forage quality with respect to crude protein (CP), neutral detergent fibre (NDF), lignin content, and *in vitro* true digestibility (IVTD). Results revealed that BMR sorghum silage had very high *in vitro* true digestibility and low lignin content. The study concluded that BMR sorghum silage will be a better alternative to corn silage for the dairy and feedlot industries. Table 2 displays a summary of the results.

Table 2: Comparison of sorghum types for forage quality

Types of sorghum	% CP	% NDF	% lignin	% IVTD
Dual Purpose Silage	6.60	46.15	4.35	75.33
Normal Silage	7.45	44.57	4.38	76.93
BMR Silage	7.41	44.91	3.34	80.00
Normal PS Silage	5.27	59.63	5.01	70.22
BMR PS Silage	5.86	56.96	4.01	75.33

Source: Bean et al. (2003)

Silage and Beef Cattle Production

Beef cattle operations are popular in the Texas High Plains. The region is the home to one of the greatest concentrations of Confined Livestock Operations (CLOs) in the world. Research has found that more than 36% of the fed beef produced annually in the United States come from the High Plains. Amosson et al. (2011) found that 42 counties in the Texas High Plains produce 88% of the fed beef consumed in the state.

Sales generated from fed beef in the Texas High Plains exceeded $11.8 billion with approximately 10.3 million head being marketed in 2010 (Guerrero et al., 2013).

One of the greatest production expenses in the cattle operations is feed. Different kinds of feedstuffs can be added in the rations for cattle, and there is nothing special about particular ingredients; however, what matters are the nutrients they provide (Harris, 2003). The role of silage in beef enterprises and the whole farm profitability cannot be over emphasized. In the Texas Panhandle, feedlots usually incorporate corn silage into finishing rations as a source of roughage. Howell et al. (2007) found that beef feed yards in the High Plains have utilized limited amounts of silages, primarily from corn in past years, but the dairies impose a much greater demand for forages and silages. Corn silage has proven to be a high quality feedstuff that supplies beef cattle diets with energy and roughage for better performance.

Hough et al. (2003) conducted a study to determine the performance of heifers fed with brown midrib forage sorghum silage (BMR) and corn silage (CS) as the roughage source in a high concentrate finishing diet. Results revealed that the brown midrib sorghum silage had a greater average daily gain (ADG) and better feed conversions compared to corn silage indicating that brown midrib sorghum silage may be an acceptable roughage source in feedlot diets.

CHAPTER III

MATERIALS AND METHODS

The study focuses on economic evaluation of silage crops under reduced irrigation in the Taxes High Plains. Dairy and feedlot industries in the High Plains are on the increase. This has resulted in a significant quantity of feed (silage) needed to keep a pace in order to sustain the business. The primary groundwater source (Ogallala Aquifer) in the Texas High Plains that supports the intensive nature of agriculture is waning rapidly. The study, therefore, analyzes the economic profitability of corn silage and sorghum silage under different water levels. It also determines the water saving potential between corn silage and sorghum silage as well as the effect of forage quality on milk yield per ton of forage dry matter.

Study Area

The study area for the research is the Texas High Plains which is made up of the Northern and the Southern High Plains of Texas. The region is the home to one of the greatest concentrations of Confined Livestock Operations (CLOs) in the world. The region is often known as the cattle feeding capital of the world. Livestock range industry remains important throughout the western portions of the High Plains. The region's climate and friendly environmental conditions has led to a progressive increase in fed cattle operations. Forty- two counties of the Texas High Plains produce 88% of the fed beef consumed in the state (Amosson et al., 2011; Amosson et al., 2015).

Besides the immeasurable impact from the livestock industry to the region's economy, crop production is also intensive. More than 25 crops are grown commercially in the High Plains. Corn, wheat, cotton, sorghum, ensilage, and hay are the predominant crops. The total value of crops sold within the region averaged about $1.7 billion annually in the 2009 to 2012 year period. The sales obtained from corn alone amounted to $688.1 million (Amosson et al., 2015).

Data Collection

Data included in this study represents production information for corn silage and sorghum silage in the study area. The variables for estimating the water response function for sorghum silage yield included 240 observations compiled from several experiments conducted during 2007 to 2014 at Texas AgriLife Research Center approximately 8 miles from Amarillo, TX. However, data for 2012 and 2013 were not available. This can be attributed to the severe drought that hit the region during the aforesaid period. The data for corn silage yield also consist of 205 observations compiled from experiments performed at State Silage Corn Performance Tests at Etter in the Texas High Plains for the period of 2009-2013.

The total available water used for production included growing season rainfall, soil water and applied irrigation water for the different trials of corn silage and sorghum silage. Information on milk produced per ton of forage dry matter for both corn silage and sorghum silage were also included in the data for the various trials of corn silage and sorghum silage.

Procedure for Analysis

A theoretical quadratic production function model for crop yield and water is given as: $Y = \beta_o + \beta_1 AW + \beta_2 AW^2 + \varepsilon$ (1)

In equation (1), Y= yield, AW= available water, β_o, β_1, β_2, = parameters to be estimated, and ε = error term. The yield of corn silage and sorghum silage were explained as a function of total available water received during the growing season. Equation (2) describes the yield (Y) as a function of growing season water received (AW). Growing season water (AW) is the amount of precipitation, irrigation water and the soil water.

$$Y = f(AW) \tag{2}$$

$$Y = \beta_o + \beta_1 AW + \beta_2 AW^2 + \varepsilon \tag{3}$$

Regression analysis is usually used to establish a relationship via an equation for predicting values of one variable given the value of another variable. It is also used for forecasting to determine future supply, demand, pricing, sales, yield, and other variables of interest in economics (Jaggi and Sivaramane, 2012).

Ordinary least squares (OLS) regression was used to estimate the effect of growing season water on crop yield. Ordinary least squares regression is a generalized linear modeling technique that can be used to model a single response variable which has been recorded on at least interval scale. The technique can be applied to single or multiple explanatory variables as well as categorical explanatory variables that have been appropriately coded (Hutcheson, 2011). Equation (3) denotes an unrestricted quadratic model where the model has not been forced through the origin but has all the parameters.

In a regression model a linear restriction statement can be placed on one or more coefficients of the explanatory variables including the intercept in the model. For the intercept in the model, the key word "intercept" is used as a variable name, and it refers to the intercept parameter in the regression model (Jaggi and Sivaramane, 2012). It must be noted that the procedure restrict the parameter associated with the variable in the model, not the variable itself. Setting the intercept equal to zero in a regression model is an example of a restricted regression model. The implication is that the model has been forced to go through the origin.

Statistical Analytical Software (SAS version 9.4) "PROC REG" procedure was used to develop models for both corn silage and sorghum silage response to water and the effect of forage quality (Crude protein, *In-vitro* digestibility, Starch and Lignin) on the amount of milk yield per ton of dry matter of the forage. The intercept for sorghum silage and corn silage in the regression models were forced to go through the origin by adding a linear restriction statement (restrict intercept = 0) to the SAS procedure. The model assumed water to be the primary input factor that influences yield, holding other variables constant. Hence, the intercept been zero implies that if there is no water there is no yield. The restricted regression model procedure was used to explain the effect of water on yield and forage quality on the quantity of milk produced for both corn silage and sorghum silage in the analysis of this study.

The direct expense information for irrigated sorghum silage and corn silage production were obtained from the projected cost and return per acre budget from the Texas Crop and Livestock Enterprise Budgets for 2013-2015. Optimization tables were built to estimate the profit maximizing levels of total available water, irrigation water and profit in dollar per acre for sorghum silage and corn silage production in the Texas High Plains. Irrigated yield per acre was multiplied by the crop price to determine the crop value per acre. Irrigation applied was also multiplied by the irrigation cost to determine growing season irrigation cost per acre. The crop value per acre was then subtracted by the irrigation cost per acre and direct expenses for the crop production to determine the profit per acre at different levels of irrigation. This was done using various combinations of sorghum silage and corn silage average price received for 2013 to 2015 when silage is delivered at the dairy and the average natural gas price for five year (2011-15) period in the Northern High Plains. For the Southern High Plains average monthly electricity price for industrial (farms) used from 2011 to 2015 in Texas and average price for sorghum silage and corn silage delivered at the dairy from 2013 to 2015 were used.

Irrigated Sorghum Silage

The relationship between irrigated sorghum silage yield and total growing season water for production was examined. The irrigated sorghum silage yield was assumed as a function of total available water (Equation 4). Ordinary least squares (OLS) regression was used to estimate the effect of total available water on irrigated sorghum silage yield. The quadratic relationship shows the amount of yield produced due to amount of total water applied (Equation 4).

$$\text{Yield} = \text{f (Total water)} \tag{4}$$

$$\text{Yield} = \beta_0 + \beta_1 \text{TW} + \beta_2 \text{TW}^2 \tag{5}$$

Since the total water model is a quadratic regression, there is a level where sorghum silage yield is at maximum. The law of diminishing returns plays a key role here. The law states that as increasing amounts of one input are added to a production process while other inputs are held constant, the amount of output added per unit of variable input will eventually decline. The maximum point is determined by solving for the marginal physical product (MPP) and then setting the MPP equal to zero to determine the optimal level. The marginal physical product (MPP_{AW}) of sorghum silage is the first derivative of the total physical product (TPP_{AW}). Total water (TW) used for sorghum silage production is made up of irrigation, precipitation and soil water present. The profit maximizing water level is determined when the marginal value product (MVP_{AW}) equals marginal factor cost (MFC_{AW}).The marginal value product is the first derivative of the total value product while the marginal factor cost is the first derivative of the total cost. Profit was derived from the relation:

$$\text{Profit} = (\text{Irrigated yield*Price}) - \text{Fixed cost} - \text{Variable cost} \qquad (6)$$

The production cost of sorghum silage is made up of fixed cost and variable cost incur during the production process. Since all irrigated growing activities in the High Plains use groundwater from the Ogallala Aquifer, variable cost varies with the amount of irrigation applied. The total direct expense other than irrigation for sorghum silage production was held constant and used as the fixed cost (FC). This value was obtained from a three year average (2013-2015) projected cost and return per acre budget for sprinkler irrigated sorghum silage in the Texas High Plains area (Appendix A). The fixed cost was $404.10/acre. The variable cost (Irrigation cost) is made up of fuel cost (FULC), cost of lubrication, maintenance and repairs (LMR), labor cost (LC), and annual investment cost (AIC), equation 7.

$$\text{Variable cost} = \text{Irrigation applied}\ (\text{FULC} + \text{LMR} + \text{LC} + \text{AIC}) \qquad (7)$$

The information involving cost of irrigation was obtained from the economics of irrigation systems (Amosson et al., 2011). Low energy precision application (LEPA) at 350 pump lift was selected for the calculation of irrigation cost. Field tests show that with LEPA, 95 to 98 percent of the irrigation water pumped gets to the crop. Water application is precise and concentrated. Center pivots equipped with LEPA applicators provide maximum water application efficiency at minimum operating pressure (New and Fipps, 2010). The FULC is the product of natural gas price and the amount of natural gas (NG) used in million cubic feet (Mcf). NG is the amount of natural gas used to pump an acre-inch of water at 350ft of pumping lift. The AIC, LMR, and LC were found to be $2.75, $4.04, and $0.75 respectively and sum up to $7.54 (Amosson et al., 2011). For this study, Irrigation applied was obtained by subtracting precipitation received during the growing season from the total optimal water (Equation 8).

$$\text{Irrigation water applied} = \text{Optimal total water} - \text{precipitation} \quad (8)$$

Irrigated Corn Silage

For irrigated corn silage, the relationship between total available water and yield were also determined. The irrigated corn silage yield was expressed as a function of total water (Equation 9). Ordinary least squares (OLS) regression was used to estimate the effect of total water on irrigated corn silage. The quadratic relationship shows the amount of yield produced due to amount of total water received (Equation 9).

$$\text{Yield} = \text{f (Total water)} \quad (9)$$

$$\text{Yield} = \beta_0 + \beta_1 \text{TW} + \beta_2 \text{TW}^2 \quad (10)$$

Since the total water model is a quadratic regression, there is a level where corn silage yield is at maximum. The maximum point is determined by solving for the marginal physical product (MPP) and then setting the MPP equal to zero and solving for the total water level to maximize profit. The marginal physical product (MPP_{AW}) of corn silage is the first derivative of the total physical product (TPP_{AW}). Total water (TW) is made up of irrigation, precipitation and soil water present. Profit is maximized at that input level where the increase in value from using an additional unit of input, marginal value product (MVP), is equal to the increase in cost associated with the use of that same unit of input, marginal factor cost (MFC). The marginal value product is the first derivative of the total value product while the marginal factor cost is the first derivative of the total cost. Profit for irrigation applied is therefore obtained from the relation:

Profit = (Irrigated yield*Price) – Fixed cost -Variable cost (11)

The production cost of corn silage is made up of fixed cost and variable cost incur during the production process. Since Texas High Plains uses groundwater from the Ogallala Aquifer to do all irrigated growing activities, variable cost varies with the amount of irrigation applied. The total direct expense other than irrigation for corn silage production was held constant and used as fixed cost (FC). This value was obtained from a three year average (2013- 2015) projected cost and return per acre budget for sprinkler irrigated corn silage in the Texas High Plains (Appendix B). The fixed cost was $671.92/acre. The variable cost (Irrigation cost) is made up of fuel cost (FULC), cost of lubrication, maintenance and repairs (LMR), labor cost (LC), and annual investment cost (AIC) equation 12.

$$\text{Variable cost} = \text{Irrigation applied}\,(\text{FULC} + \text{LMR} + \text{LC} + \text{AIC}) \qquad (12)$$

The information involving cost of irrigation was obtained from the economics of irrigation systems (Amosson et al., 2011). Low energy precision application (LEPA) at 350 pumping lift was selected for the calculation of irrigation cost. The FULC is the product of natural gas price and the amount of natural gas (NG) used in million cubic feet (Mcf). NG is the amount of natural gas used to pump an acre-inch of water at 350ft of pumping lift. The AIC, LMR, and LC were found to be $1.92, $4.04, $0.52 respectively and sum up to $6.48 (Amosson et al., 2011). Irrigation applied was obtained by subtracting precipitation received during the growing season from the total optimal water equation 13. Irrigation water applied = Optimal total water – average precipitation (13)

Comparative analysis of water use between corn silage and sorghum silage

Available inventory of 249,000 dairy cows in the Texas High Plains (USDA/ NASS, 2015) was used to calculate the water saving potential of replacing corn silage with sorghum silage considering the indirect water used required to grow corn silage feed component of a dairy cow feed mix. Yields of 27 and 21 tons per acre for irrigated corn silage and sorghum silage (Amosson, 2015) respectively were used in the calculation of the acreage required to grow the corn silage and sorghum silage needed. The corn silage feed requirement in the ration of the dairy cow was calculated from the dairy publication (Guerrero et al., 2012).

Each animal's daily feed requirement is based on the information available in the dairy publication. The estimated corn silage requirement was 4,180,711 tons. Forage sorghum silage has 80 to 90% of the energy value of corn silage on dry matter basis; therefore, 1.11 pounds of sorghum silage will have the same energy value equal to one pound of corn silage (Rick, 1994). The indirect water usage is calculated from the estimated feed required by a dairy cow annually, which is the amount of water needed to grow the feed component of the silage in acre-feet.

The number of cows in the inventory multiplied by the total irrigation water used will be the indirect water use. Four approaches were used to estimate potential water saving if corn silage is replaced with sorghum silage under different conditions:

1. Corn silage is fed to dairy cows (Baseline Scenario I)

2. Corn silage (CS) is replaced by sorghum (SS) at 100% (SS Scenario II)
3. Corn silage (CS) is replaced by 50% irrigated sorghum silage and 50% dryland sorghum silage (SSDS Scenario III)
4. Corn silage (CS) is replaced by 50% irrigated corn silage and 50% dryland sorghum silage (DS Scenario IV)

Effect of forage quality on milk production per ton of forage dry matter

Ordinary least squares (OLS) regression was used to predict the effect of forage quality with respect to crude protein (CP), lignin, starch, and *in-vitro* true digestibility (IVTD) of corn silage and sorghum silage on milk yield. The general specification of the model is given by:

Milk produced = f (forage quality)

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_n X_n + \mathcal{E},$$

where Y is the milk produced, X_1, X_2…………………, X_n represent the explanatory variables of corn silage and sorghum silage forage quality which includes crude protein, lignin, starch, and *in-vitro* true digestibility, $\mathcal{E}$ is the error term, β_0 and β_n are parameters to be estimated.

In order to ensure that the independent variables in the regression model are predicting individually and no correlation exists among them, a multicollinearity diagnostic test was conducted. Multicollinearity, or near-linear dependence, is a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. If not addressed properly, it can have a significant impact on the quality and stability of the fitted regression model (Joshi et al., 2012). Tolerance (an indicator of how much collinearity that a regression analysis can tolerate) and Variance

Inflation Factor (VIF- an indicator which quantifies the severity of multicollinearity in an ordinary least squares regression analysis) are commonly used measures to check collinearity among explanatory variables.

A VIF above 5 or 10 and a tolerance below 0.1 is an indication that the associated regression coefficients are poorly estimated because of multicollinearity (Pallant, 2005; Joshi et al., 2012). The results in Table 3 revealed that there is no significant collinearity among the explanatory variables that may bias their prediction on the effect of forage quality (CP, IVTD, lignin, and starch) on milk produced by feeding corn silage and sorghum silage to dairy animals.

Table 3: Collinearity diagnostic test on explanatory variables

	Corn silage		**Sorghum silage**	
Explanatory Variables	Tolerance	VIF	Tolerance	VIF
Crude protein	0.747	1.338	0.852	1.173
IVTD	0.781	1.281	5.068	0.197
Starch	0.218	4.595	0.876	1.142
Lignin	0.572	1.748	0.985	1.015

The restricted model was used to explain the analysis for the effect of corn silage and sorghum silage forage quality on milk yield. All other variables that influence milk yield were held content and only the variables crude protein (CP), in-vitro true digestibility (IVTD), starch, and lignin content of both silages were concentrated. The assumption underlining the use of the restricted model was to look at the effect of these explanatory variables, therefore if the animal is not fed with the silage no milk is produced.

CHAPTER IV

RESULTS AND DISCUSSION

The study analyzes the economic evaluation of silage crops under reduced irrigation in the Taxes High Plains. A quadratic response function was used to estimate the relationship between corn silage and sorghum silage yields and total water from rainfall, soil moisture, and irrigation water used in the production process. A comparative analysis of water use between corn silage and sorghum silage and an estimate of potential water saving were also carried out. Crude protein (CP), lignin, starch, and *in-vitro* true digestibility (IVTD) were used to predict the effect of forage quality of corn silage and sorghum silage on the amount of milk produced. Models were developed to determine the appropriate input level of total available water and irrigation water to maximize yield and profit as well as the effect of CP, IVTD, lignin, and starch on milk production**.**

Total available water

The models examine irrigated sorghum silage and irrigated corn silage yields as a function of total available water in the Northern and Southern High Plains of Texas. Using economics of irrigation system (Amosson et al., 2011) natural gas price and sorghum silage market price were used to determine different levels of total available water to maximize profit in the Northern Texas High Plains while the price of electricity was used in place of natural gas in the Southern Texas High Plains to compute the different levels of total available water that maximizes profit. The quadratic regression model revealed that total available water has a statistically significant effect on sorghum silage and corn silage yields.

Sorghum Silage and Corn Silage Model Results in the Northern High Plains

Irrigated sorghum silage

The ordinary least square regression (OLS) results relating sorghum silage to growing total available water for both the restricted and unrestricted models are shown in Table 4. The coefficient of determination of the restricted model was significant at both 0.01 and 0.05 alpha levels with R^2 value of 0.97. The implication is that 97% of the variation in sorghum silage yield is explained by total available water received by the crop. The restricted model has no intercept. The coefficient of determination was high for the restricted model because the study focused only on the water factor and considered other variables constant.

Table 4: Result showing restricted and unrestricted model relating sorghum silage to total water received.

	Unrestricted Model			Restricted Model		
Independent Variable	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	-19.66	8.337	0.0192			
TW	3.412	0.684	0.0001	1.8050	0.0651	0.0001
TW^2	-0.0693	0.014	0.0001	-0.0373	0.0025	0.0001
R^2	0.096			0.97		
Adjusted R^2	0.088			0.96		

The estimates of total available water and total available water squared are also significant at 1%. The production function developed from the restricted model above is as follows:

Restricted Model

$$Y = 1.8050AW - 0.0373AW^2 \qquad (14)$$

The level of total available water required to maximize sorghum silage yield is calculated by solving for the MPP_{AW} and then setting the MPP_{AW} equal to zero.

$$MPP_{AW} = 1.805 - 0.0746\ AW \quad (15)$$

$$AW = 1.805/0.0746 = 24.20 \text{ acre inches}$$

The level of total available water required to maximize sorghum silage yield from the restricted model is 24.20 acre inches. The yield at this optimal level of total available water is 22 tons/acre. Since this level of water may not be economically profitable looking at irrigation cost, the level of total available water is determined for various prices of sorghum silage and natural gas. The profit maximizing available total available water is determined by setting MVP_{AW} equal to MFC_{AW} and solving for the total available water required to make a profit with respect to the price of natural gas and sorghum silage at hand. A model used in previous studies (Almas et al., 2000; Amosson et al., 2001; Almas et al., 2001; Amosson et al., 2011) was used to determine the amount of natural gas needed to pump an acre-inch of water at 350 feet of pumping lift, equation (16).

$$NG = 0.0038*L + 0.0088*Psi - [(7.623E\text{-}6)*Psi*(L) - (3.3E\text{-}6)*L^2 \quad (16)$$

where, NG= quantity of natural gas, L = system left in feet and Psi = system pressure per square inch. A Low Energy Precision Application (LEPA) center pivot system with 350' lift and 15 system pressure per square inch was used to calculate the quantity of natural gas needed to pump an acre-inch of water. The value for NG was 1.018.

The total cost function is therefore written as:

$$TC = FC + (1.018P_{NG} + 4.04 + 0.75 + 2.75)\ AW \quad (17)$$

$$TC = FC + (1.018P_{NG} + 7.54)\ AW$$

From equation (17) the marginal factor cost (MFC) is therefore written as:

$MFC_{AW} = 1.018P_{NG} + 7.54$ (18)

The marginal value product is also written as:

$MVP_{AW} = (1.805\text{-}0.0746AW)\ P_Y$ (19)

where, P_Y = price of the sorghum silage. Equating MFC_{AW} to MVP_{AW}, the different total water levels at different combinations of sorghum silage and natural gas prices are obtained from the equation (20).

$AW= [1.805\text{-}\{(1.018P_{NG} +7.54)/P_Y\}/0.0746]$ (20)

Profit maximization levels of total water obtained from the equation (20) for sorghum silage prices between \$35 and \$51, natural gas prices between \$2 and \$5 are presented in Table 5.

Table 5: Optimal levels of total available water in acre inches for sorghum silage under different combinations of natural gas and sorghum silage price.

	Price of sorghum silage ($/ton)								
$/Mcf	**35.00**	**37.00**	**39.00**	**41.00**	**43.00**	**45.00**	**47.00**	**49.00**	**51.00**
2.00	20.53	20.73	20.94	21.10	21.24	21.37	21.49	21.60	21.70
2.50	20.33	20.54	20.77	20.93	21.08	21.22	21.35	21.46	21.57
3.00	20.14	20.36	20.59	20.77	20.93	21.07	21.20	21.32	21.43
3.50	19.94	20.17	20.42	20.60	20.77	20.92	21.06	21.18	21.30
4.00	19.75	19.99	20.25	20.44	20.61	20.77	20.91	21.05	21.17
4.50	19.55	19.80	20.07	20.27	20.45	20.62	20.77	20.91	21.04
5.00	19.36	19.62	19.90	20.11	20.30	20.47	20.63	20.77	20.90

The optimal levels of total available water that will maximize the net return increases as the price of sorghum silage increases and declines as the price of natural gas increases. Producers will prefer silage price to go up at a lower natural gas price. Given a sorghum silage market price of \$43/ton and natural gas price of \$3.5/Mcf, a producer will maximize profit by using 20.77 acre-inches of total available water unlike when total available water is at a low sorghum silage market price and high natural gas price. For instance, at a natural gas price of $5/Mcf and sorghum silage price of $45/ton, the total available water that is economically feasible for production is 20.47 acre-inches. Considering the average price of sorghum silage from 2013 to 2015 in Texas High Plains which is $43/ton and natural gas price of $4/Mcf, the total available water to use in order to make profit is 20.61 acre-inches.

The quantity of irrigation water required in the total available water for production will depend on the amount of rainfall and soil moisture during the production period. For example, the average rainfall received during sorghum silage and corn silage trials at Texas AgriLife Research Station for the growing season of May to October from 2007-2014 was 8.0 inches. The irrigation water component of the total available water was calculated using the average 8.0 inches of rainfall received during the growing period in the study area. The different levels of optimal irrigation water used at different combinations of sorghum silage and natural gas prices are presented in Table 6.

Table 6: Optimal levels of irrigation water in acre inches for sorghum silage under different combinations of natural gas and sorghum silage price**.**

	Price of sorghum silage ($/ton)								
$/Mcf	**35.00**	**37.00**	**39.00**	**41.00**	**43.00**	**45.00**	**47.00**	**49.00**	**51.00**
2.00	12.53	12.73	12.94	13.10	13.24	13.37	13.49	13.60	13.70
2.50	12.33	12.54	12.77	12.93	13.08	13.22	13.35	13.46	13.57
3.00	12.14	12.36	12.59	12.77	12.93	13.07	13.20	13.32	13.43
3.50	11.94	12.17	12.42	12.60	12.77	12.92	13.06	13.18	13.30
4.00	11.75	11.99	12.25	12.44	12.61	12.77	12.91	13.05	13.17
4.50	11.55	11.80	12.07	12.27	12.45	12.62	12.77	12.91	13.04
5.00	11.36	11.62	11.90	12.11	12.30	12.47	12.63	12.77	12.90

Considering the 8.0 inches of rainfall received, at $3.5/Mcf of natural gas and $45/ton of sorghum silage, a producer will be able to maximize profit by applying 12.92

acres-inches of irrigation water. However, at the same sorghum silage sales price and higher natural gas price, the producer will be using less amount of irrigation. For example, at a natural gas price of $5/Mcf and a sorghum silage price of $45/ton, 12.47 acre- inches of irrigation water will be the optimal irrigation level. Using the mean price of $43/ton of sorghum silage from the 2013-2015 budget and natural gas price of $4/Mcf, the profit maximizing irrigation water to apply is 12.61 acre-inches.

The optimal profit levels for sorghum production under alternate combinations of natural gas and sorghum silage price are shown in Table 7.

Table 7: Maximum profit in dollar per acre for irrigated sorghum silage production under alternate combinations of natural gas and sorghum silage price.

	Price of sorghum silage ($/ton)								
$/Mcf	**35.00**	**37.00**	**39.00**	**41.00**	**43.00**	**45.00**	**47.00**	**49.00**	**51.00**
2.00	63	102	143	183	222	262	301	341	380
2.50	52	92	133	173	212	252	292	331	370
3.00	42	82	123	163	203	242	282	321	360
3.50	32	72	113	153	193	233	272	312	351
4.00	22	62	104	143	183	223	262	302	342
4.50	11	52	94	134	174	214	253	293	333
5.00	2	42	84	124	164	204	244	284	323

Applying growing season irrigation water from the study area, at $4/Mcf of natural gas and $47/ton of sorghum silage, producers can receive profit of $262/acre. The profit reduces as the natural gas price increases from $2/Mcf to $5/Mcf. At natural gas price of $5/Mcf and sorghum silage sales price of $41/ton, the profit received by producers is $124/acre. Using the average price ($43/ton) of sorghum silage from the 2013-2015 sorghum silage budget and natural gas price of $4/Mcf, the profit farmers will receive is $183/acre. The highest profit producers can obtain is $380/acre at a $2/Mcf and $51/ton of sorghum silage.

Irrigated corn silage

Irrigated corn silage is a high water use crop and very sensitive to water deficit. The ordinary least square regression (OLS) result relating corn silage to growing total available water for the restricted model is shown in Table 8.

Table 8: Result showing restricted and unrestricted regression model result relating corn silage to total water received.

	Unrestricted Model			Restricted Model		
Independent Variable	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	-77.983	26.46	0.0036			
TW	7.3490	1.808	0.0001	2.0242	0.0763	0.0001
TW^2	-0.1216	0.031	0.0001	-0.0317	0.0024	0.0001
R^2	0.10			0.99		
Adjusted R^2	0.09			0.99		

The coefficient of determination of the restricted model was significant at 0.05 alpha level with R^2 value of 0.99. The implication is that 99% of the variation in corn silage yield was caused by total available water received by the crop. The coefficient of determination was high for the restricted model because the study concentrated only on the water factor and considered other variables constant. The estimates of total available water and total available water squared are significant at 1% alpha level. The production function developed from the restricted model is shown in equation 21. Restricted model for corn silage.

$$Y = 2.0242AW - 0.0317AW^2 \qquad (21)$$

The profit maximizing total available water is calculated by solving for MPP_{AW} and then setting the MPP_{AW} equal to zero.

$$MPP_{AW} = 2.0242 - 0.0634AW$$

$AW = 2.0242/0.0634 = 31.92$ acre-inches

From the calculations, the level of total available water required to maximize corn silage yield from the restricted model is 31.92 acre-inches. The yield of corn silage at this total available water level is 32 tons/acre. Since this level of water may not be economically feasible considering irrigation cost, the level of available water is determined for various prices of corn silage and natural gas. The profit maximizing total available water is determined by setting MVP_{AW} equal to MFC_{AW} and solve for the total available water. Using the Low Energy Precision Application (LEPA) center pivot system with 350' lift, the following equations were developed:

$$TC = FC + (1.018P_{NG} + 4.04 + 0.52 + 1.92)\ AW \qquad (22)$$

$$TC = FC + (1.018P_{NG} + 6.48)\ AW$$

From equation (22) the marginal factor cost (MFC) is written as:

$$MFC_{AW} = 1.018P_{NG} + 6.48 \qquad (23)$$

The marginal value product is also written as:

$$MVP_{AW} = (2.0242 - 0.0634AW)P_Y \qquad (24)$$

where, P_Y = price of the corn silage. Equating MFC_{AW} to MVP_{AW}, the different total available water levels at different combinations of corn silage and natural gas prices are obtained from equation (25).

$$AW = [2.0242 - \{(1.018P_{NG} + 6.48)/\ P_Y\}/0.0634] \qquad (25)$$

The profit maximization levels of total available water obtained from equation (25) for corn silage prices between \$40 and \$56, natural gas prices between \$2 and \$5 are presented in Table 9.

Table 9: Optimal levels of total water in acre inches for corn silage under different combinations of natural gas and corn silage price.

	Price of corn silage ($/ton)								
$/Mcf	**40.00**	**42.00**	**44.00**	**46.00**	**48.00**	**50.00**	**52.00**	**54.00**	**56.00**
2.00	28.59	28.75	28.89	29.02	29.14	29.25	29.36	29.45	29.54
2.50	28.39	28.56	28.71	28.85	28.98	29.09	29.20	29.30	29.40
3.00	28.19	28.37	28.53	28.67	28.81	28.93	29.05	29.15	29.25
3.50	27.99	28.18	28.35	28.50	28.64	28.77	28.89	29.01	29.11
4.00	27.79	27.99	28.16	28.33	28.48	28.61	28.74	28.86	28.97
4.50	27.59	27.80	27.98	28.15	28.31	28.45	28.59	28.71	28.82
5.00	27.39	27.61	27.80	27.98	28.14	28.29	28.43	28.56	28.68

The optimal levels of total available water that is economically feasible increases as the price of corn silage increases and decreases as the price of natural gas increases. Given corn silage market price at $46/ton and natural gas price of $3.5/Mcf, a farmer will maximize profit by using 28.50 acre-inches of total available water (Table 9). With natural gas price of $5/Mcf and corn silage market price of $50/ton, the total available water that will be needed for production to maximize profit is also 28.29 acre-inches. The total available water decreases as natural gas price increases and increases as corn silage price increases and natural gas price remains the same. With this, farmers will prefer the fuel price to remain constant and the corn silage price to go up to earn more profit. Given the average price of corn silage from the 2013-2015 budget to be $48/ton and natural gas price to be $4/Mcf, the profit maximizing total available water is 28.48 acre-inches. Considering an average rainfall of 8.0 inches in the study area, the different levels of irrigation water that are available to producers at different combinations of natural gas and corn silage market price are presented in Table 10.

Table 10: Optimal levels of irrigation water in acre inches for corn silage under different combinations of natural gas and corn silage price.

	Price of corn silage ($/ton)								
$/Mcf	**40.00**	**42.00**	**44.00**	**46.00**	**48.00**	**50.00**	**52.00**	**54.00**	**56.00**
2.00	20.59	20.75	20.89	21.02	21.14	21.25	21.36	21.45	21.54
2.50	20.39	20.56	20.71	20.85	20.98	21.09	21.20	21.30	21.40
3.00	20.19	20.37	20.53	20.67	20.81	20.93	21.05	21.15	21.25
3.50	19.99	20.18	20.35	20.50	20.64	20.77	20.89	21.01	21.11
4.00	19.79	19.99	20.16	20.33	20.48	20.61	20.74	20.86	20.97
4.50	19.59	19.80	19.98	20.15	20.31	20.45	20.59	20.71	20.82
5.00	19.39	19.61	19.80	19.98	20.14	20.29	20.43	20.56	20.68

The greatest irrigation water level (21.54 acre-inches) is found at a natural gas price of $2/Mcf and corn silage market price of $56/ton. Irrigation water available to farmers continues to decline as the natural gas price increases and increases as the price of corn silage goes up. Due to variations in precipitation in the study area, the amount of irrigation water producers will apply will be influenced by the amount of rainfall received during that growing season.

More rainfall will lead to less irrigation water whereas less rainfall will call for more irrigation water. As a result the profit received by producers will also vary significantly. The optimal irrigation level for corn silage price of $48/ton and natural gas price of $4/Mcf is 20.48 acre-inches. The profit farmers can receive increases as the price of corn silage increases and declines as the price of natural gas increases. At natural gas price of $3/Mcf and corn silage price of $44/ton, producers will receive a profit of $377/acre of corn silage. However, at a natural gas price of $5/Mcf, the aforesaid profit decreases to $320/acre when corn silage price remains the same ($44/ton). The different profit levels available to producers at different combinations of corn silage and natural gas prices are displayed in Table 11.

Table 11: Optimum profit in dollar per acre for irrigated corn silage production under alternate combinations of natural gas and corn silage price.

	Price of corn silage ($/ton)								
$/Mcf	**40.00**	**42.00**	**44.00**	**46.00**	**48.00**	**50.00**	**52.00**	**54.00**	**56.00**
2.00	282	344	405	466	527	588	649	710	771
2.50	268	329	390	452	513	574	635	696	757
3.00	255	316	377	438	500	561	622	683	744
3.50	239	301	362	423	485	546	607	668	729
4.00	225	287	348	410	471	532	593	655	716
4.50	211	273	334	396	457	518	580	641	702
5.00	197	259	320	382	443	505	566	627	689

From the corn silage budget of 2013-2015, the average price of corn silage is $48/ton, therefore, the profit received at $4/Mcf price of natural gas is $471/acre. The maximum profit producers can obtain from the different natural gas and corn silage price is $771/acre.

Sorghum Silage and Corn Silage Model Results in the Southern High Plains

Irrigated sorghum silage

Crop production on the Southern High Plains of Texas depends greatly on groundwater drawn from the Ogallala Aquifer. Agricultural water rules related to pumpage restrictions, in addition to improving water use efficiency, have been enacted in the Southern High Plains of Texas in order to manage groundwater resources (Pete et al., 2009). The Southern High Plains uses electricity instead of natural gas to pump water for corn silage and sorghum silage production.

A producer who uses an irrigation system with a pumping lift of 350 feet and operates at a pump discharge pressure of 15 pounds per square inch (psi) would require a 1.018 quantity of natural gas to apply or pump an acre-inch of water. If the producer uses electricity a factor of 14.12 is multiply by 1.018 (14.12 x 1.018) to get 14.37 kWh equivalent power to pump an acre-inch of water **(**Derrel et al, 2010). Equation (26) shows total available water function at different prices of electricity and sorghum silage price.

$$AW= [1.805-\{(14.37P_E + 7.54)/P_Y\}/0.0746] \quad (26)$$

where, AW = total available water, 14.37 = kWh of electricity needed to pump an acre inch of water, P_E = price of electricity and P_Y = price of sorghum silage. The profit maximization levels of total available water obtained from equation (26) for sorghum silage price between $35 and $51 and electricity price between $0.054and $0.104 are presented in Table 12.

Table 12: Optimal levels of total water in acre inches for sorghum silage under different combinations of electricity and sorghum silage price.

	Price of sorghum silage ($/ton)								
$/kWh	**35.00**	**37.00**	**39.00**	**41.00**	**43.00**	**45.00**	**47.00**	**49.00**	**51.00**
0.054	21.01	21.18	21.37	21.51	21.63	21.74	21.85	21.94	22.03
0.064	20.96	21.13	21.32	21.46	21.58	21.70	21.80	21.90	21.99
0.074	20.90	21.08	21.27	21.41	21.54	21.66	21.76	21.86	21.95
0.084	20.85	21.03	21.22	21.37	21.50	21.61	21.72	21.82	21.92
0.094	20.79	20.97	21.17	21.32	21.45	21.57	21.68	21.78	21.88
0.104	20.74	20.92	21.12	21.27	21.41	21.53	21.64	21.75	21.84

The level of total available water increases as the price of sorghum silage increases and reduces as the price of electricity increases. For instance, at electricity price of $0.054/kWh and sorghum silage price of $41/ton, the total available water required to maximize profit is 21.51 acre-inches. If the price of electricity stays the same ($0.054/kWh) and the price of sorghum silage changes from $41/ton to $ 45/ton, the total available water also increases to 21.74 acre-inches. On the contrary, when the price of electricity increases from $0.054/kWh to $0.084/kWh and sorghum silage price stays at $41.00/ton, the total available water required reduces from 21.51 to 21.37 acre-inches, a reduction of 0.14 acre-inches of total available water is observed (Table 12). At this price combination, producers will have access to less total available water for production compared to when the electricity price is low and a high sorghum silage price. The profit maximizing total available water to apply using the mean price of sorghum silage ($43/ton) and the average electricity price ($0.074/kWh) is 21.54 acre-inches.

Given average precipitation of 8.0 inches in the study area, the different levels of irrigation water that are available to producers at different combinations of electricity and sorghum silage market price are presented in Table 13.

Table 13: Optimal levels of irrigation water in acre inches for sorghum silage under different combinations of electricity and sorghum silage price

	Price of sorghum silage ($/ton)								
$/kWh	**35.00**	**37.00**	**39.00**	**41.00**	**43.00**	**45.00**	**47.00**	**49.00**	**51.00**
0.054	13.01	13.18	13.37	13.51	13.63	13.74	13.85	13.94	14.03
0.064	12.96	13.13	13.32	13.46	13.58	13.70	13.80	13.90	13.99
0.074	12.90	13.08	13.27	13.41	13.54	13.66	13.76	13.86	13.95
0.084	12.85	13.03	13.22	13.37	13.50	13.61	13.72	13.82	13.92
0.094	12.79	12.97	13.17	13.32	13.45	13.57	13.68	13.78	13.88
0.104	12.74	12.92	13.12	13.27	13.41	13.53	13.64	13.75	13.84

The highest irrigation water level (14.03 acre-inches) available to producers is found at electricity price of $0.054/kWh and sorghum silage market price of $51/ton. The level of irrigation water rises as the price of sorghum silage increases and declines as the price of electricity increases. This implies that at a higher price level of electricity producers will have less irrigation water compared to when the price of electricity is low. However, the amount of precipitation received during the growing season will dictate the quantity of irrigation water producers are likely to apply to supplement the rainfall received. Profit is one of the key elements producers look at in a business venture.

The amount of profit received at each optimal level of irrigation from the combinations of electricity and sorghum silage price is displayed in Table 14.

Table 14. Maximum profit in dollar per acre for irrigated sorghum silage production under alternate combinations of electricity and sorghum silage price.

	Price of sorghum silage ($/ton)								
$/kWh	**35.00**	**37.00**	**39.00**	**41.00**	**43.00**	**45.00**	**47.00**	**49.00**	**51.00**
0.054	89	128	169	208	248	287	326	365	405
0.064	86	125	166	205	244	284	323	363	402
0.074	83	122	163	202	242	281	320	360	399
0.084	80	119	160	200	239	278	317	357	396
0.094	77	116	157	197	236	275	315	354	393
0.104	74	113	154	194	233	273	312	351	390

Using growing season irrigation water applied, at $0.054/kWh of electricity and $45.00/ton of sorghum silage, producers can make a profit of $287/acre. The profit declines as electricity price increases from $0.054/kWh to $0.104/kWh. At electricity price of $0.084/kWh and sorghum silage sales price of $45/ton, a profit of $278/acre is received. Using the mean market price ($43/ton) for sorghum silage from the 2013-2015 budget, the profit producers can receive at electricity price of $0.074/kWh is $242/acre. The highest profit producers can obtain is $405/acre. The value is obtained at a price combination of $51/ton for sorghum silage and $0.054/kWh of electricity.

Irrigated corn silage

Irrigated corn silage also shows the same trend as irrigated sorghum silage. As the price of corn silage increases the level of total available water also rises. Conversely, total available water levels decrease as the price of electricity goes up. Producers will prefer corn silage prices to go up at constant electricity price in order to earn more profit. The amount of irrigation water required to meet total water requirement of the crop depends on rainfall received during the growing period.

Variations in rainfall received affects the amount of irrigation applied from one growing season to another, which determines the profit producers accrue due to differences in the pumping cost of the water. Although farmers do not have total control over rainfall received, their decision on how much irrigation water to apply can be influenced by the irrigation well capacity and amount of rainfall received during the growing season. The different levels of total available water to producers at different combinations of corn silage and electricity price are presented in Table 15.

Table 15: Optimal levels of total water in acre inches for corn silage under different combinations of electricity and corn silage price.

	Price of corn silage ($/ton)								
$/kWh	**40.00**	**42.00**	**44.00**	**46.00**	**48.00**	**50.00**	**52.00**	**54.00**	**56.00**
0.054	29.08	29.22	29.34	29.45	29.55	29.65	29.74	29.82	29.89
0.064	29.03	29.16	29.29	29.40	29.51	29.60	29.69	29.78	29.85
0.074	28.97	29.11	29.24	29.35	29.46	29.56	29.65	29.73	29.81
0.084	28.91	29.06	29.19	29.30	29.41	29.51	29.61	29.69	29.77
0.094	28.86	29.00	29.13	29.26	29.37	29.47	29.56	29.65	29.73
0.104	28.80	28.95	29.08	29.21	29.32	29.42	29.52	29.61	29.69

At a given price of $46/ton of corn silage and $0.054/KWh of electricity, the total available water needed for production is 29.45 acre-inches. However, this level of total available water decreases to 29.30 acre-inches when electricity price goes up to $0.084/kWh and corn silage price stays at $46/ton. Farmers will get enough profit at a lower price of electricity and a higher price of corn silage. For instance, at electricity price of $0.064/kWh and corn silage price of $48/ton, the total available water to the producer to maximize profit is 29.51 acre-inches. At this same price ($48/ton) of corn silage, the total available water reduces to 29.37 acre-inches when electricity price increases to \$0.094/kWh. The irrigation water for the different combinations of corn silage and electricity prices, given 8.0 inches of average precipitation in the study area, are presented in Table16.

Table 16: Optimal levels of irrigation water in acre inches for corn silage under different combinations of electricity and corn silage price.

	Price of corn silage (\$/ton)								
\$/kWh	**40.00**	**42.00**	**44.00**	**46.00**	**48.00**	**50.00**	**52.00**	**54.00**	**56.00**
0.054	21.08	21.22	21.34	21.45	21.55	21.65	21.74	21.82	21.89
0.064	21.03	21.16	21.29	21.40	21.51	21.60	21.69	21.78	21.85
0.074	20.97	21.11	21.24	21.35	21.46	21.56	21.65	21.73	21.81
0.084	20.91	21.06	21.19	21.30	21.41	21.51	21.61	21.69	21.77
0.094	20.86	21.00	21.13	21.26	21.37	21.47	21.56	21.65	21.73
0.104	20.80	20.95	21.08	21.21	21.32	21.42	21.52	21.61	21.69

The different irrigation water levels show the same trend as the total available water for corn silage and electricity prices in Table 15. As irrigation water levels increase from lower corn silage price to higher price, total available water levels also decrease from lower electricity price to higher price (Table 16). The highest irrigation water at different combinations of corn silage price and electricity price that producers can apply to maximize profit is 21.89 acre-inches. At corn silage price of \$48/ton and electricity price of \$0.064/kWh, producers have to apply 21.51 acre- inches of irrigation water to make profit compared to when electricity price is \$0.084/kWh and corn silage is \$46/ton which will require 21.30 inches of irrigation water (Table 16). Using the electricity price of \$0.074/kWh and the average sorghum silage price (\$48/ton) from the 2013-2015 budget for corn silage, the profit maximizing irrigation water is 21.46 acre-inches. The different profit levels available to producers at different combinations of electricity and corn silage prices are presented in Table 17.

Table 17: Maximum profit in dollar per acre for irrigated corn silage production under alternate combinations of electricity and corn silage price.

	Price of corn silage ($/ton)								
$/kWh	**40.00**	**42.00**	**44.00**	**46.00**	**48.00**	**50.00**	**52.00**	**54.00**	**56.00**
0.054	318	380	441	501	562	623	684	745	806
0.064	314	375	436	497	558	619	680	741	802
0.074	310	371	432	493	554	615	676	737	798
0.084	306	367	428	489	550	611	672	733	794
0.094	302	363	424	485	546	607	668	729	790
0.104	298	359	420	481	542	603	664	725	786

The profit levels decline at a higher price of electricity but increases as the price of corn silage goes up. For instance, at electricity price of $0.064/ kWh and corn silage price of $46/ton, the profit producers can receive is $497/acre. On the contrary, at a lower price of electricity ($0.054/kWh) with the same price of corn silage ($46/ton), the profit increases to $501/acre. At corn silage average price of $48/ton and electricity price of $0.074/kWh, the profit producers can receive is $554/acre. The maximum profit available to producers at various combinations of corn silage and electricity price is $806/acre.

Comparative analysis of water use between corn silage and sorghum silage and estimate of potential water saving

A greater percentage of the water used in producing the feed requirement came from the irrigated field. From the baseline scenario where corn silage is fed to 249,000 dairy cows, a total of 258,068 acre-feet of water will be needed to produce the required 4,180,711 tons of corn silage in the feed mix. This quantity of feed will require 154,841 acres to grow the corn silage. For scenario two, a 100% replacement of corn silage with sorghum silage will require 239,692 acre-feet of water to grow 4,646,340 tons of sorghum silage to meet the feed requirement.

A total of 221,254 acres will be needed to produce the sorghum silage feed requirement. There is 11% increase in total feed (tons) of sorghum silage more than corn silage. The reason for the increase in sorghum silage required was because the corn silage yield of 27 tons per acre is greater than sorghum silage yield of 21 tons per acre. The amount of total indirect water needed when sorghum silage is used to replace corn silage decreased by 18,376 acre-feet. This is due to more irrigation water required by corn silage compared to sorghum silage.

Scenario three assumes corn silage is replaced by 50% irrigated sorghum silage and 50% dryland sorghum silage. The water required for this combination is 135,519 acre-feet. The water saving potential if corn silage is replaced by 50% irrigated sorghum silage and 50% dryland sorghum silage is 138,222 acre-feet.

The final scenario uses 50% irrigated corn silage and 50% dryland sorghum silage to replace corn silage. The acre- feet of water required for this scenario is 129,034. This will results in a water savings of 110, 658 acre-feet. It can be deduced from the four scenarios that a combination of 50% irrigated sorghum silage and 50% dryland sorghum silage has the greatest water saving potential. The dairy cow inventory, silage acres for production, total feed required, and indirect water use for corn silage and sorghum silage are presented in Table 18.

Table 18. Dairy cow inventory, silage acres required for feed, and water use

Description	2015
Total Dairy Cows	249,000
Corn Silage (CS) acres	154,841
Total Feed (tons with CS)	4,180,711
Sorghum Silage (SS) acres	221,254
Total Feed (tons with **SS**)	4,646,340
Water Req. (ac-ft. with **CS**) **Scenario I**	258,068
Water Req. (ac-ft. with **SS**) **Scenario II**	239,692
Water Req. (ac-ft. with **SSDS**) **Scenario III**	119,846
Water Req. (ac-ft. with **CSDS**) **Scenario IV**	129,034
Water Saving Potential **Scenario I-III**	**138,222**
Water Saving Potential **Scenario II-IV**	110,658

Based on 20 inches of irrigation water for corn silage, 13 inches for irrigated sorghum silage, 27 ton per acre for corn silage and 21 tons per acre for sorghum silage (Amosson, 2015)

Effect of forage quality of corn silage on milk production

Multiple regression analysis was conducted to determine the effect of crude protein (CP), *in vitro* true digestibility after 24 hours of incubation in rumen fluid (IVTD24), lignin, and starch on milk produced per ton of forage dry matter of corn silage. The results revealed that there is a statistically significant relationship between the forage quality (CP, IVTD24, lignin, and starch) and the amount of milk produced per ton of forage dry matter. The coefficient of determination of the restricted model was significant at both 0.01 and 0.05 alpha level with R^2 value of 0.999. The implication is that 99.9% of the variation in milk produced per ton of forage dry matter is explained by the forage attributes. Table 19 presents a summary of the regression analysis for corn silage forage quality on milk produced per ton of dry matter.

Table 19: Result showing restricted and unrestricted regression model relating forage quality of corn silage to milk produced per ton of forage dry matter.

Explanatory Variables	Unrestricted Model Estimate	Unrestricted Model Standard Error	Unrestricted Model p-Value	Restricted Model Estimate	Restricted Model Standard Error	Restricted Model p-Value
Intercept	-408.42	239.52	0.00012			
CP	36.30	8.246	0.0001	42.086	7.552	0.0001
IVTD24	55.15	3.443	0.0001	49.772	1.397	0.0001
Starch	-16.64	1.554	0.0116	-15.656	1.450	0.0001
Lignin	-166.05	16.99	0.0001	-187.73	11.318	0.0001
R^2	0.904			0.999		
Adjusted R^2	0.902			0.999		

From the restricted model in Table 19, crude protein had a statistically significant relationship with milk produced per ton of forage dry matter of corn silage at p-value of 0.0001. The estimate for crude protein was found to be 42.09. The value (42.09) implies that a unit increase in crude protein of the forage quality of corn silage will increase the amount of milk produced per ton of forage dry matter by 42.09 pounds holding other variables constant. Additionally, IVTD24 also had a positive relationship with milk produced per ton of forage dry mater at 1% significant level. The estimate for IVTD24 was 49.78. This means that a unit increase in IVTD24 will increase the amount of milk yield per ton of forage dry matter by 49.78 pounds holding other variables constant.

IVTD measures digestibility and can be used to estimate energy. A higher value of IVTD presents a better forage quality which enhances milk production. Lignin and starch had a negative significant relationship with the amount of milk produced per ton of forage dry matter at p-value of 0.0001. The estimate for lignin and starch were -187.73 and -15.66 respectively. The implication for these estimates are that a unit increase in lignin and starch will decrease the amount of milk produced per ton of dry matter by 187.73 and 15.66 pounds respectively holding other variables constant.

Lignin is the primary chemical factor limiting cell wall digestibility; therefore, too much of it in the forage cannot be digested by the animal (Oliver et al., 2004). Also too much starch in the rumen of the animal causes ruminal acidosis (occurs when the pH of the rumen falls to less than 5.5) and depresses ruminal digestion. This makes the animal become sick, resulting in poor digestion and milk production and low feed efficiency (Neal et al., 2008). The inverse relation of lignin and starch to milk produced, provide an indication that the present level of lignin and starch in corn silage are enough to enhance milk production.

Effect of forage quality of sorghum silage on milk production

Ordinary least squares (OLS) regression was used to determine the effect of sorghum silage forage quality in terms of crude protein (CP), starch, and *in -vitro* true digestibility after 48 hours of incubation in rumen fluid (IVTD48) on milk produced per ton of forage dry matter. The results revealed that there is a statistically significant relationship between the forage quality of sorghum silage and the amount of milk produced per ton of dry matter of the forage.

The coefficient of determination of the restricted model was significant at both 0.01 and 0.05 alpha level with R^2 value of 0.984. The implication is that 98.4% of the variation in milk produced per ton of forage dry matter is explained by sorghum silage forage quality. The restricted model in Table 20 shows that crude protein had a positive significant relationship with milk produce per ton of forage dry matter of sorghum silage at 5% significance level.

Table 20: Result showing restricted and unrestricted regression model relating forage quality of sorghum silage to milk produced per ton of dry matter.

Independent Variable	Unrestricted Model Estimate	Unrestricted Model Standard Error	Unrestricted Model p-Value	Restricted Model Estimate	Restricted Model Standard Error	Restricted Model p-Value
Intercept	-1578.8	331.98	0.0001			
CP	60.64	19.87	0.0025	45.179	20.480	0.0283
IVTD48	44.93	4.459	0.0001	25.668	1.948	0.0001
Starch	14.35	3.264	0.0001	16.690	3.372	0.0001
Lignin	1.068	4.490	0.8830	-6.060	7.460	0.4170
R^2	0.47			0.984		
Adjusted R^2	0.46			0.983		

The estimate for crude protein, which is approximately 45.18, implies that a unit increase in crude protein of sorghum silage forage quality will increase the amount of milk produce per ton of dry matter by 45.18 pounds holding any other variable constant. *In-vitro* true digestibility after 48 hours of incubation in rumen fluid (IVTD48) also had a statistically significant positive relationship with milk produced per ton of forage dry mater at p-value of 0.0001 with an estimate value of approximately 25.67. This implies that a unit increase in IVTD48 of sorghum silage forage quality will increase the amount of milk produce per ton of forage dry matter by 25.67 pounds. Starch had a positive significant relationship with the amount of milk produced per ton of forage dry matter at 1% alpha level. The estimate for starch was 16.69 which implies that a unit increase in starch of the forage quality of sorghum silage will increase the amount of milk produced per ton of forage dry matter by 16.69 pounds when other variable are held constant. The lignin content of sorghum silage was not significant. This means that lignin does not have effect on milk yield of sorghum silage.

Milk yield per ton of silage dry matter of corn silage and sorghum silage

The milk produced with respect to crude protein, *in-vitro* true digestibility, starch, and lignin content of corn silage and sorghum silage were calculated using the mean values and the parameter estimates from the regression analysis. Sorghum silage lignin was not used in the sorghum silage milk prediction because it was not significant in the sorghum silage regression model. Table 21 shows the mean values of the explanatory variable for both corn silage and sorghum silage and the estimates obtained from the regression analysis.

Table 21: Explanatory variables, mean and parameter estimates for corn silage and sorghum silage

Corn silage			**Sorghum silage**		
Variables	Mean	Estimate	Variables	Mean	Estimate
Crude protein	8.18	42.086	Crude protein	7.58	45.179
IVTD24	77.87	49.772	IVTD48	77.45	25.668
Starch	37.15	-15.656	Starch	15.45	16.690
Lignin	3.41	-187.730	Lignin	4.31	-6.060

Corn silage calculation:

Milk = 42.09 (Crude protein) + 49.78 (IVTD24) -15.66 (Starch) -187.73(lignin)

= 42.09 (8.18) + 49.77 (77.87) -15.66 (37.15) -187.73(3.41)

= 344.30 + 3875.59 - 581.77- 640.16

= 2,998 pounds per ton of silage dry matter

The predicted milk from the corn silage forage quality as far as crude protein, *in-vitro* true digestibility, starch, and lignin content of the silage are concerned is 2,998 pounds (liquid) per ton of silage dry matter, when all other variables are held constant.

Sorghum silage calculation:

Milk = 45.18 (Crude protein) + 25.67 (IVTD48) + 16.69 (Starch)

= 45.18 (7.58) + 25.67 (77.45) + 16.69 (15.40)

= 342.46 + 1988.14 + 257.03

= 2,588 pounds per ton of silage dry matter

For sorghum silage the predicted milk with respect to crude protein, *in-vitro* true digestibility, and starch, content of the silage is 2,588 pounds (liquid) per ton of silage dry matter, when all other variables remain the same.

From the two milk prediction equations, corn silage milk produced is more than sorghum silage. There is approximately16% increase in corn silage milk yield more than sorghum silage. Considering the current market price of milk in Texas which is $16 per cwt, (100 pounds = 1cwt) the revenue generated from the whole of corn silage milk produced is $480 (16 x 29.98) while sorghum silage is $414 (16 x 25.88). There is $66 in revenue more of corn silage than sorghum silage. However, corn silage cost more than sorghum silage.

Economic analysis of feeding dairy cows with corn silage and sorghum per year

The feed components of a dairy cow was based on the information available in the dairy publication (Guerrero et al., 2012). The feed is made up of alfalfa, corn silage, sorghum silage, small grain silage, concentrate, cotton seed, protein, and minerals. Two approaches were considered with respect to the cost of feeding dairy cows with corn silage and sorghum silage. The first approach, the cost of corn silage and sorghum silage were calculated holding constant other variables in the feed component of the animals.

The analysis was centered on buying the silage to feed the cows per year. Table 22 presents the ration requirements giving as fed to dairy cows in tons per year.

Table 22: Dairy cow yearly ration (feed components)

Input	As fed (tons/year)
Alfalfa	1.77
Corn silage	11.24
Sorghum silage	1.87
Small grains silage	3.68
Concentrate	3.44
Cotton seed	0.89
Protein	0.84
Minerals	0.22
Total	23.95

Source: Guerrero et al. (2012)

The corn silage component of a dairy cow feed per year is 11.24 tons while sorghum silage is 1.87 tons (Guerrero et al., 2012). Corn silage and sorghum silage were treated separately. According to Rick (1994) the ratio of corn silage to sorghum silage on dry matter basis is 1: 1.11 for same energy. Considering the corn silage and sorghum silage components in the feed mix, a total of 12.92 tons of corn silage will be needed in the feed mix while 14.35 tons of sorghum silage will be required when replacing corn silage with sorghum silage.

The price of corn silage, sorghum silage and natural gas were obtained from estimated costs and returns per acre budget for irrigated corn silage and irrigated sorghum silage from 2013 to 2015 in the Texas High Plains. The average price of corn silage is $48/ton while sorghum silage is $43/ton for the three years. However, the mean price of natural gas for the same period (2013-2015) is $4/Mcf. The total direct expenses of corn silage and sorghum silage are $671.92 and $404.10 per acre, respectively. For a given number of 45 dairy cows, a total of 581 tons of corn silage will be needed as part of the feed component in the ration formulation to feed the cows per year. At a given price of $48/ton, the cost of 581 tons of corn silage required to formulate a ration for 45 dairy animals will be $27,907. If the number of cows are increased from 45 to 135, a total of 1,744 tons of corn silage will be required at a cost of $83,722. The cost of corn silage increases as the number of cows' increases as well as the quantity of corn silage required. Table 23 displays the costs the producer will incur for buying corn silage to feed dairy cows at a given number per year.

Table 23: The cost of feeding dairy cows with corn silage (CS) per year

Dairy Cows	Feed/cow/year (tons)	Quantity/year (tons)	Price ($/ton)	Feed cost/year ($)
45	12.92	581	48	27,907
90	12.92	1,163	48	55,814
135	12.92	1,744	48	83,722
180	12.92	2,326	48	111,629
225	12.92	2,907	48	139,536

For sorghum silage, a total of 646 tons will be required to formulate ration for 45 dairy animals in a year. At a given price of $43/ton of sorghum silage, a cost of $27,767 will be incurred for feeding 646 tons of sorghum silage per year. For a given number of 135 dairy animals, the farmer will require 1,937 tons of sorghum silage in a year to feed the animals at a cost of $83,302. The feed cost increases as the quantity of sorghum silage and the number of dairy animals increases. It can be deduced from the feed cost that at the same number of animals and silage requirement, farmers will spend relatively less on sorghum silage feed cost per year. Table 24 presents the quantity of sorghum silage that will be needed to formulate ration for the same dairy cows if corn silage is replaced with sorghum silage 100% and the associated feed cost.

Table 24: The cost of feeding dairy cows with sorghum silage (SS) per year

Dairy Cows	Feed/cow/year (tons)	Quantity/year (tons)	Price ($/ton)	Feed cost/year ($)
45	14.35	646	43	27,767
90	14.35	1,292	43	55,535
135	14.35	1,937	43	83,302
180	14.35	2,583	43	111,069
225	14.35	3,229	43	138,847

Table 25 presents the feed cost comparison between corn silage and sorghum silage for different number of dairy cows per year if corn silage is replaced wholly with sorghum silage in the feed mix of dairy cows holding other variables in the feed mix constant.

Table 25: Feed cost comparison between corn silage and sorghum silage for different number of dairy cows per year.

	Corn silage	Sorghum silage	Difference in total cost CS and SS ($)
Dairy cows	Feed cost ($)	Feed cost ($)	
45	27,907	27,767	140
90	55,814	55,535	280
135	83,722	83,302	420
180	111,629	111,069	560
225	120,931	120,325	606

The second approach is to calculate the cost of corn silage and sorghum silage required if the farmer decides to grow the silage. Corn silage uses 20 inches of irrigation water and produces 27 tons per acre while sorghum silage uses 13 inches of irrigation water and yields at 21 tons per acre (Amosson, 2015). At a given price of $4/Mcf of natural gas, a total of 430.37 inches of water will be needed to grow 581 tons of corn silage to feed 45 dairy animals at irrigation cost of $1,721 per year. For a given number of 135 dairy cows, a total irrigation water of 1,291.85 acre-inches will be required to grow 1,744 tons of corn silage at irrigation cost of $5,167 per year. The irrigation cost increases as the number of animals and the feed required increases.

It can be said that an increase in fuel cost will lead to increase in irrigation cost for corn silage production. The total acreage required to grow the feed also increases as the number of dairy cows increases. For example, 21.52 acres will be needed to grow the feed required by 45 dairy cows per year. When the cows' number increase to 225, a total of 107.67 acres will be needed to grow the required feed per year (Table 26).

Table 26: Irrigation cost for growing corn silage per acre to feed dairy cows per year

Dairy Cows	Feed/cow/ year (tons)	Quantity (tons/year)	Acres required	Water (acre-inches)	Price of natural gas ($/Mcf)	Irrigation Cost/year ($)
45	12.92	581	21.52	430.37	4.00	1,721
90	12.92	1,163	43.07	861.48	4.00	3,446
135	12.92	1,744	64.59	1,291.85	4.00	5,167
180	12.92	2,326	86.15	1,722.96	4.00	6,892
225	12.92	2,907	107.67	2,153.40	4.00	8,614

For sorghum silage, a total of 399.88 inches of irrigation water will be required to grow 646 tons of the silage to feed 45 dairy animals at irrigation energy cost of $1,600 per year. At a higher number of dairy animals (180), which requires 2,583 tons of sorghum silage to meet the feed requirement, a total of 1,599 inches of water will be needed to grow sorghum silage at irrigation cost of $6,396 per year. At the same number of animals and quantity of feed required per year, the farmer spend less on sorghum silage as far as irrigation cost is concerned. This is due to the quantity of irrigation water required to grow the feed in the dairy cow ration when replaced with corn silage.

The total acreage required to grow the feed increases as the number of dairy cows increases. At a given number of 135 dairy cows, 92.24 acres will be needed to grow sorghum silage to meet the feed mix for the dairy cows per year. When the cows' number increase to 225, a total of 153.76 acres will be needed to grow the required feed per year.

Table 27 displays the irrigation cost for producing the sorghum silage feed required in the ration of dairy cows when replaced with corn silage.

Table 27: Irrigation cost for growing sorghum silage per acre to feed dairy cows per year

Dairy Cows	Feed/cow/ year (tons)	Quantity (tons/year)	Acres Required	Water (acre-inches)	Price of natural gas ($/Mcf)	Irrigation cost/year ($)
45	14.35	646	30.76	399.88	4.00	1,600
90	14.35	1,292	61.52	799.76	4.00	3,199
135	14.35	1,937	92.24	1,199.12	4.00	4,796
180	14.35	2,583	123.00	1,599.00	4.00	6,396
225	14.35	3,229	153.76	1,998.88	4.00	7,996

The production cost comparison between corn silage and sorghum silage feed required to meet the dietary requirement of different number of dairy cows per year are presented in Table 28.

Table 28: Production cost comparison between corn silage and sorghum silage

	Corn silage (CS)			Sorghum silage (SS)			
Dairy Cows	Irrigation cost ($/year)	Direct expense without irrigation ($/year)	Total cost ($/year)	Irrigation cost ($/year)	Direct expense without irrigation ($/year)	Total cost ($/year	Difference in total cost CS and SS ($/year)
45	1,721	14,459	16,180	1,600	12,430	14,030	2,150
90	3,446	28,942	32,388	3,199	24,860	28,059	4,329
135	5,167	43,401	48,568	4,796	37,274	42,070	6,498
180	6,892	57,885	64,777	6,396	49,704	56,100	8,677
225	8,614	72,346	80,960	7,996	62,134	70,130	10,830

Direct expense without irrigation per acre = $671.92 for corn silage and $404.10 for sorghum silage.

The analysis from the two approaches has clearly shown that it is profitable to use sorghum silage compared to corn silage whether buying or growing the silage. At a given number of 45 dairy cows the farmer saves $140 on feed cost if the cows are fed with sorghum silage per year. The savings on feed cost for feeding sorghum silage increases as the number of animals increases. For instance, $420 will be saved on 135 dairy cows for feeding sorghum silage to meet their feed requirement per year. There is approximately 15% extra cost incurred for growing corn silage than growing sorghum silage per year to feed the same number of cows. There is also water savings if sorghum silage is grown. For instance, the irrigation water required to grow corn silage and sorghum silage needed in the feed mix of 225 dairy cows requires 154.52 inches of irrigation water more for corn silage.

For a given number of 180 dairy cows the total production cost of corn silage incurred per year is $64,777 whereas sorghum silage will cost $56,100. This results in a production cost savings of $8,677 when sorghum silage replaces corn silage. If the farmer decides to buy the silage to meet the feed component for the 180 dairy cows, a total of $560 will be saved on total feed cost for purchasing sorghum silage per year. Although, there is 16% increase in milk yield of corn silage with regards to forage quality in enhancing milk production, the amount of water needed to grow corn silage is relatively high. Given the same number of dairy cows and feed required in tons per year, the farmer growing sorghum silage saves approximately 15% on production cost per year. At the present time when water scarcity has become a global concern coupled with unpredictable climate change, it is economically prudent to consider sorghum silage especially in the Texas High Plain.

According to Harris (2003) corn silage and sorghum silage are usually fed to dairy cows at 30% dietary dry matter. It is suggested that feeding dairy cows with 35% or 45% dietary dry matter of sorghum silage or increasing the concentrate component of the feed to meet dietary requirements can increase the quantity of milk produced. However, this is dependent on the animals' ability to feed and digest beyond 30% forage dry matter and the cost of the additional concentrate to meet the requirement. Improving the crude protein, *in-vitro* true digestibility, and starch content of sorghum silage can also increase the quantity of milk produced per ton of the forage dry matter as well as saving producers' money on production costs.

CHAPTER V

CONCLUSION

Summary of Results

The role played by the crop and livestock production in the Texas High Plains cannot be overestimated. The ever growing dairy and feedlot industries in the region has led to high demand of silage from livestock industry; however, the dominant source of water (Ogallala Aquifer) for crops production and livestock operations is declining at an alarming rate. The study analyzes the economic profitability of silage crops under reduced irrigation in the Texas High Plains. The specific objectives were to: 1) Estimate water response function for irrigated corn silage and sorghum silage, 2) Use the input response function to determine optimum levels of input to maximize profit for corn silage and sorghum silage, 3) Perform a comparative analysis of water use between corn silage and sorghum silage and estimate potential water saving, and 4) Predict the effect of forage quality of corn silage and sorghum silage on milk production per ton of dry matter of the forage.

Irrigated corn silage and sorghum silage yield were explained as a function of total available water received during the growing season. The quantity of irrigation water required throughout the growing season depends on the amount of rainfall received at the growing season. Total available water had an appreciable significant effect on corn silage and sorghum silage yield when the model was restricted. The restricted models had a higher R^2 values than the actual fit of the observed data. The R^2 values from the restricted models for corn silage and sorghum silage with respect to total available water received were 99% and 97% respectively.

The profit producers can receive in the Northern Texas High plains for irrigated sorghum silage ($43/ton) and corn silage ($48/ton) at a natural gas price of $4/Mcf are $183/acre and $471/acre, respectively. In the Southern Texas High Plains, the profit available to producers for sorghum silage ($43/ton) and corn silage ($48/ton) with electricity price of $0.074/kWh are $242/acre and $554/acre, respectively. The yield and price difference between corn silage and sorghum silage led to the differences in the profit received per acre, although the production cost of sorghum silage is relatively cheaper than corn silage. The quantity of irrigation water discharge to the crop per acre for the different combinations of corn silage and sorghum silage price and electricity price is higher compared to natural gas.

A total of 258,068 acre-feet of water will be needed to produce 4,180,711 tons of corn silage whereas 271,037 acre-feet of water will be required to grow 4,646,340 tons of sorghum silage to meet the feed (silage) component of dairy cows numbering 249,000. More water will be required to produce the needed silage component of the dairy cows if corn silage is replaced 100% by sorghum silage. However, the amount of water saved if corn silage is replaced by 50% irrigated sorghum silage and 50% dryland sorghum silage is 138,222 acre-feet.

The crude protein, *in-vitro* true digestibility, starch, and lignin content of corn silage and sorghum silage forage quality on milk yield showed no significant collinearity at a tolerance level of 0.1 and a VIF level of 5 or 10 to bias the prediction. The R^2 values for sorghum silage and corn silage forage quality on milk yield per ton of forage dry matter were 0.98 and 0.99 respectively. The implication for sorghum silage is that 98% of the variation in milk produced per ton of silage dry mater is caused by crude protein (CP) content, starch, and *in -vitro* true digestibility (IVTD48) holding other variables constant. A comparison of milk yield per ton of silage dry matter between sorghum silage and corn silage showed a higher amount in favor of corn silage. There is 16 % increase in milk yield of corn silage more than sorghum silage.

Although there is more increase in milk yield, it is economically profitable to feed the dairy cows with sorghum silage compared to corn silage as far as buying or growing both silages are concerned. There is 15% more on production cost for corn silage in the feed component of dairy cows per year. For a given number of 225 dairy cows the total production cost of corn silage incurred per year is $80,960 whereas sorghum silage is $70,130. This results in a production cost savings of $10,830 when sorghum silage replaces corn silage. If the farmer decides to buy the silage to meet the feed component for the 225 dairy cows, a total of $120,931 will be incurred on corn silage per year while $120,325 will be spent on sorghum silage per year. An amount of $606 will be saved on total feed cost for purchasing sorghum silage to meet the feed component of the 225 dairy cows per year.

The decision to feed dairy cows with 35% or 45% dietary dry matter of sorghum silage or increase the concentrate component of the feed to meet dietary requirements can increase the quantity of milk produced. However, this is dependent on the animals' ability to feed and digest beyond 30% forage dry matter and the cost of the additional concentrate to meet the requirement. Improvement in crude protein, *in-vitro* true digestibility, and starch content of sorghum silage will increase the quantity of milk produced per ton of the forage dry matter.

Considering global concerns on water scarcity coupled with unpredictable climate changes, it is economically prudent to consider sorghum silage especially in the Texas High Plains where the groundwater (Ogallala Aquifer) is waning.

Limitation of the Study

The study was limited to only corn silage and sorghum silage and did not include other silage crops for preparing ration to feed dairy cows.

Recommendation for Future Research

Further studies are needed to look at the profitability of switching completely from natural gas to electricity to pump water for corn silage and sorghum silage production in the Texas High Plains.

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APPENDIX A

IRRIGATED SORGHUM SILAGE BUDGET

Year			2013	2014	2015	
Revenue						
	Quantity	Unit	$/Unit	$/Unit	$/Unit	Average
Sorghum silage	21	Tons	54.00	40.00	36.30	43.43
Variable Cost						
Production Costs ($/Acre)						
Customs						
Harvest and Haul- Sorghum Silage			152.25	180.18	184.80	172.41
Fertilizer Application			5	5.5	5.5	5.33
Fertilizer Application-ANH3			10	11.75	11.75	11.17
Fertilizer						
Fertilizer (P) Dry			42.6	31.2	36	36.60
Fertilizer (N) ANH3			87	66.12	69.6	74.24
Herbicide						
Herbicide and Apply sorghum sudan			7.58	7.8	7.95	7.78
Insecticide						
Insecticide and Apply sorghum Silage			3.18	3.33	3.38	3.30
Seed						
Seed- sorghum			12.81	13.19	13.3	13.10
Miscellaneous						
Crop Insurance sorghum silage irrigated			23.4	22.46	22.46	22.77
Machinery Labor						
Tractor/self- propelled			10.7	11.75	9.4	10.62
Diesel Fuel						
Tractor / Self - propelled			9.58	7.9	6.8	8.09
Gasoline						
Pickup/ General Use Equipment			10.61	9.99	9.19	9.93
Repairs and Maintenance						
Pickup/ General Use Equipment			0.48	3.76	3.76	2.67
Tractor / Self - propelled			5.9	8.52	2.81	5.74
Implements			6.28	19.04	11.71	12.34
Interest on Credit Lines			9.19	7.32	7.39	7.97
Total Direct Expenses without irrigation			**396.56**	**409.81**	**405.80**	**404.10**

Adapted from Estimated Costs and Returns per Acre Sorghum Silage, Bt, Sprinkler Irrigated (NG) Panhandle Extension District-1 (2013-15). Average natural gas price for 2013-15 is $4/Mcf

APPENDIX B

IRRIGATED CORN SILAGE BUDGET

Year			2013	2014	2015	Average
Revenue						
	Quantity	Unit	$/Unit	$/Unit	$/Unit	Average
Corn silage	27	Tons	60.00	44.40	40.30	48.23
Variable Cost						
Production Costs ($/Acre)						
Customs						
Harvest and Haul- Corn Silage			195.75	231.66	237.60	221.67
Fertilizer Application-ANH3			10	11.75	11.75	11.17
Fertilizer						
Fertilizer (P)	Liquid		54.6	47.4	51.00	51.00
Fertilizer (N)	ANH3		63	47.88	50.40	53.76
Fertilizer(N)	Liquid		53.04	49.92	42.90	48.62
Herbicide						
Herbicide corn - Preplant			16.87	17.36	17.70	17.31
Herbicide corn- post -Plant			15.25	15.69	16.00	15.65
Insecticide						
Maticide			20.6	21.52	22.00	21.37
Insecticide and Apply Corn Silage			25.28	26.42	26.90	26.20
Seed						
Seed- corn silage			106	112	115.00	111.00
Miscellaneous						
Crop Insurance Corn silage irrigated			26.7	25.63	25.63	25.99
Machinery Labor						
Tractor/self- propelled			10.7	13.4	13.28	12.46
Diesel Fuel						
Tractor / Self - propelled			11.57	9.58	10.07	10.41
Gasoline						
Pickup/ General Use Equipment			10.41	9.99	9.19	9.86
Repairs and Maintenance						
Pickup/ General Use Equipment			2.13	3.76	3.76	3.22
Tractor / Self - propelled			6.64	9.75	4.45	6.95
Implements			7.13	19.01	13.73	13.29
Interest on Credit Lines			13.56	11.12	11.33	12.00
Total Direct Expenses without irrigation			**649.23**	**683.84**	**682.69**	**671.92**

Adapted from Estimated Costs and Returns per Acre Corn Silage, Bt, Sprinkler Irrigated (NG) Panhandle Extension District-1 (2013-15). Average natural gas price for 2013-15 is $ 4/Mcf

APPENDIX C

SORGHUM SILAGE DATA

Year	Method (Center Pivot)	Irrigation (acre-inches)	Rainfall (inches)	Rainfall/ /Irrigation and Soil Water (inches)	Yield (tons/acre)
2007	CP	9.95	8.10	18.05	20.6
2007	CP	9.95	8.10	18.05	23.2
2007	CP	9.95	8.10	18.05	22.3
2007	CP	9.95	8.10	18.05	23.3
2007	CP	9.95	8.10	18.05	25.0
2007	CP	9.95	8.10	18.05	25.4
2007	CP	9.95	8.10	18.05	18.9
2007	CP	9.95	8.10	18.05	17.5
2007	CP	9.95	8.10	18.05	20.7
2007	CP	9.95	8.10	18.05	15.6
2007	CP	9.95	8.10	18.05	15.7
2007	CP	9.95	8.10	18.05	20.4
2007	CP	9.95	8.10	18.05	20.9
2007	CP	9.95	8.10	18.05	23.1
2007	CP	9.95	8.10	18.05	21.1
2007	CP	9.95	8.10	18.05	23.3
2007	CP	9.95	8.10	18.05	20.8
2007	CP	9.95	8.10	18.05	16.7
2007	CP	9.95	8.10	18.05	23.3
2007	CP	9.95	8.10	18.05	15.3
2007	CP	9.95	8.10	18.05	16.4
2007	CP	9.95	8.10	18.05	16.6
2007	CP	9.95	8.10	18.05	17.1
2007	CP	9.95	8.10	18.05	19.0
2007	CP	9.95	8.10	18.05	15.1
2007	CP	9.95	8.10	18.05	19.4
2007	CP	9.95	8.10	18.05	19.4
2007	CP	9.95	8.10	18.05	13.8
2007	CP	9.95	8.10	18.05	13.4
2007	CP	9.95	8.10	18.05	15.8
2007	CP	9.95	8.10	18.05	17.1

2007	CP	9.95	8.10	18.05	16.0
2007	CP	9.95	8.10	18.05	14.1
2007	CP	9.95	8.10	18.05	19.7
2007	CP	9.95	8.10	18.05	18.9
2007	CP	9.95	8.10	18.05	14.3
2007	CP	9.95	8.10	18.05	20.0
2007	CP	9.95	8.10	18.05	16.4
2007	CP	9.95	8.10	18.05	19.7
2007	CP	9.95	8.10	18.05	19.0
2008	CP	13.0	12.60	25.60	32.5
2008	CP	13.0	12.60	25.60	21.1
2008	CP	13.0	12.60	25.60	22.3
2008	CP	13.0	12.60	25.60	20.7
2008	CP	13.0	12.60	25.60	19.6
2008	CP	13.0	12.60	25.60	20.8
2008	CP	13.0	12.60	25.60	24.1
2008	CP	13.0	12.60	25.60	20.0
2008	CP	13.0	12.60	25.60	21.7
2008	CP	13.0	12.60	25.60	21.6
2008	CP	13.0	12.60	25.6	16.8
2008	CP	13.0	12.60	25.60	17.6
2008	CP	13.0	12.60	25.60	12.9
2008	CP	13.0	12.60	25.60	15.6
2008	CP	13.0	12.60	25.60	15.3
2008	CP	13.0	12.60	25.60	20.4
2008	CP	13.0	12.60	25.60	23.6
2008	CP	13.0	12.60	25.60	20.3
2008	CP	13.0	12.60	25.60	19.2
2008	CP	13.0	12.60	25.60	19.7
2008	CP	13.0	12.60	25.60	19.5
2008	CP	13.0	12.60	25.60	17.0
2008	CP	13.0	12.60	25.60	20.7
2008	CP	13.0	12.60	25.60	20.3
2008	CP	13.0	12.60	25.60	18.0
2008	CP	13.0	12.60	25.60	17.2
2008	CP	13.0	12.60	25.60	19.7
2008	CP	13.0	12.60	25.60	19.6
2008	CP	13.0	12.60	25.60	19.7
2008	CP	13.0	12.60	25.60	25.0
2008	CP	13.0	12.60	25.60	18.8
2008	CP	13.0	12.60	25.60	21.5
2008	CP	13.0	12.60	25.60	15.0

2008	CP	13.0	12.60	25.60	21.7
2008	CP	13.0	12.60	25.60	21.6
2008	CP	13.0	12.60	25.60	16.8
2008	CP	13.0	12.60	25.60	18.2
2008	CP	13.0	12.60	25.60	20.5
2008	CP	13.0	12.60	25.60	19.1
2008	CP	13.0	12.60	25.60	18.6
2009	CP	22.3	8.50	30.80	18.4
2009	CP	22.3	8.50	30.80	18.6
2009	CP	22.3	8.50	30.80	18.3
2009	CP	22.3	8.50	30.80	15.3
2009	CP	22.3	8.50	30.80	17.5
2009	CP	22.3	8.50	30.80	18.4
2009	CP	22.3	8.50	30.80	20.5
2009	CP	22.3	8.50	30.80	21.9
2009	CP	22.3	8.50	30.80	19.7
2009	CP	22.3	8.50	30.80	21.2
2009	CP	22.3	8.50	30.80	16.9
2009	CP	22.3	8.50	30.80	17.8
2009	CP	22.3	8.50	30.80	16.4
2009	CP	22.3	8.50	30.80	23.6
2009	CP	22.3	8.50	30.80	16.1
2009	CP	22.3	8.50	30.80	20.8
2009	CP	22.3	8.50	30.80	18.9
2009	CP	22.3	8.50	30.80	25.2
2009	CP	22.3	8.50	30.80	21.5
2009	CP	22.3	8.50	30.80	20.8
2009	CP	22.3	8.50	30.80	19.6
2009	CP	22.3	8.50	30.80	21.5
2009	CP	22.3	8.50	30.80	19.1
2009	CP	22.3	8.50	30.80	18.5
2009	CP	22.3	8.50	30.80	22.3
2009	CP	22.3	8.50	30.80	19.2
2009	CP	22.3	8.50	30.80	17.9
2009	CP	22.3	8.50	30.80	23.3
2009	CP	22.3	8.50	30.80	18.9
2009	CP	22.3	8.50	30.80	25.0
2009	CP	22.3	8.50	30.80	18.8
2009	CP	22.3	8.50	30.80	21.5
2009	CP	22.3	8.50	30.80	17.2
2009	CP	22.3	8.50	30.80	20.3
2009	CP	22.3	8.50	30.80	21.6
2009	CP	22.3	8.50	30.80	26.2

2009	CP	22.3	8.50	30.80	24.8
2009	CP	22.3	8.50	30.80	20.4
2009	CP	22.3	8.50	30.80	25.1
2009	CP	22.3	8.50	30.80	16.5
2010	CP	15.5	7.30	22.80	26.1
2010	CP	15.5	7.30	22.80	30.3
2010	CP	15.5	7.30	22.80	19.6
2010	CP	15.5	7.30	22.80	26.7
2010	CP	15.5	7.30	22.80	17.4
2010	CP	15.5	7.30	22.80	24.2
2010	CP	15.5	7.30	22.80	23.6
2010	CP	15.5	7.30	22.80	23.7
2010	CP	15.5	7.30	22.80	25.3
2010	CP	15.5	7.30	22.80	22.9
2010	CP	15.5	7.30	22.80	29.8
2010	CP	15.5	7.30	22.80	30.2
2010	CP	15.5	7.30	22.80	28.2
2010	CP	15.5	7.30	22.80	21.4
2010	CP	15.5	7.30	22.80	24.8
2010	CP	15.5	7.30	22.80	26.2
2010	CP	15.5	7.30	22.80	20.3
2010	CP	15.5	7.30	22.80	26.6
2010	CP	15.5	7.30	22.80	23.6
2010	CP	15.5	7.30	22.80	19.8
2010	CP	15.5	7.30	22.80	27.6
2010	CP	15.5	7.30	22.80	23.9
2010	CP	15.5	7.30	22.80	21.8
2010	CP	15.5	7.30	22.80	18.9
2010	CP	15.5	7.30	22.80	29.2
2010	CP	15.5	7.30	22.80	21.9
2010	CP	15.5	7.30	22.80	25.4
2010	CP	15.5	7.30	22.80	24.4
2010	CP	15.5	7.30	22.80	22.9
2010	CP	15.5	7.30	22.80	27.2
2010	CP	15.5	7.30	22.80	24.1
2010	CP	15.5	7.30	22.80	20.0
2010	CP	15.5	7.30	22.80	23.0
2010	CP	15.5	7.30	22.80	24.7
2010	CP	15.5	7.30	22.80	22.7
2010	CP	15.5	7.30	22.80	32.8
2010	CP	15.5	7.30	22.80	21.2
2010	CP	15.5	7.30	22.80	19.4
2010	CP	15.5	7.30	22.80	30.7

2010	CP	15.5	7.30	22.80	25.7
2011	CP	20.3	2.00	22.30	21.2
2011	CP	20.3	2.00	22.30	22.6
2011	CP	20.3	2.00	22.30	18.7
2011	CP	20.3	2.00	22.30	23.5
2011	CP	20.3	2.00	22.30	17.6
2011	CP	20.3	2.00	22.30	19.4
2011	CP	20.3	2.00	22.30	22.3
2011	CP	20.3	2.00	22.30	25.4
2011	CP	20.3	2.00	22.30	17.8
2011	CP	20.3	2.00	22.30	18.1
2011	CP	20.3	2.00	22.30	19.6
2011	CP	20.3	2.00	22.30	20.7
2011	CP	20.3	2.00	22.30	20.9
2011	CP	20.3	2.00	22.30	23.7
2011	CP	20.3	2.00	22.30	19.7
2011	CP	20.3	2.00	22.30	23.3
2011	CP	20.3	2.00	22.30	21.7
2011	CP	20.3	2.00	22.30	28.8
2011	CP	20.3	2.00	22.30	21.7
2011	CP	20.3	2.00	22.30	21.8
2011	CP	20.3	2.00	22.30	21.4
2011	CP	20.3	2.00	22.30	16.5
2011	CP	20.3	2.00	22.30	22.1
2011	CP	20.3	2.00	22.30	22.0
2011	CP	20.3	2.00	22.30	20.9
2011	CP	20.3	2.00	22.30	20.2
2011	CP	20.3	2.00	22.30	21.6
2011	CP	20.3	2.00	22.30	20.5
2011	CP	20.3	2.00	22.30	16.1
2011	CP	20.3	2.00	22.30	21.2
2011	CP	20.3	2.00	22.30	20.2
2011	CP	20.3	2.00	22.30	22.6
2011	CP	20.3	2.00	22.30	17.9
2011	CP	20.3	2.00	22.30	17.7
2011	CP	20.3	2.00	22.30	23.7
2011	CP	20.3	2.00	22.30	22.4
2011	CP	20.3	2.00	22.30	20.1
2011	CP	20.3	2.00	22.30	21.5
2011	CP	20.3	2.00	22.30	21.1
2011	CP	20.3	2.00	22.30	22.3
2014	CP	13.8	9.20	23.00	21.4
2014	CP	13.8	9.20	23.00	22.3

2014	CP	13.8	9.20	23.00	17.1
2014	CP	13.8	9.20	23.00	32.4
2014	CP	13.8	9.20	23.00	22.1
2014	CP	13.8	9.20	23.00	20.8
2014	CP	13.8	9.20	23.00	25.4
2014	CP	13.8	9.20	23.00	17.3
2014	CP	13.8	9.20	23.00	20.1
2014	CP	13.8	9.20	23.00	25.7
2014	CP	13.8	9.20	23.00	14.8
2014	CP	13.8	9.20	23.00	30.2
2014	CP	13.8	9.20	23.00	29.1
2014	CP	13.8	9.20	23.00	18.6
2014	CP	13.8	9.20	23.00	18.4
2014	CP	13.8	9.20	23.00	20.0
2014	CP	13.8	9.20	23.00	23.6
2014	CP	13.8	9.20	23.00	23.2
2014	CP	13.8	9.20	23.00	29.3
2014	CP	13.8	9.20	23.00	32.5
2014	CP	13.8	9.20	23.00	28.0
2014	CP	13.8	9.20	23.00	23.9
2014	CP	13.8	9.20	23.00	15.5
2014	CP	13.8	9.20	23.00	23.8
2014	CP	13.8	9.20	23.00	18.1
2014	CP	13.8	9.20	23.00	21.6
2014	CP	13.8	9.20	23.00	26.2
2014	CP	13.8	9.20	23.00	36.6
2014	CP	13.8	9.20	23.00	17.7
2014	CP	13.8	9.20	23.00	29.5
2014	CP	13.8	9.20	23.00	19.8
2014	CP	13.8	9.20	23.00	16.8
2014	CP	13.8	9.20	23.00	20.2
2014	CP	13.8	9.20	23.00	21.6
2014	CP	13.8	9.20	23.00	19.7
2014	CP	13.8	9.20	23.00	27.7
2014	CP	13.8	9.20	23.00	19.6
2014	CP	13.8	9.20	23.00	28.5
2014	CP	13.8	9.20	23.00	26.5
2014	CP	13.8	9.20	23.00	20.4

APPENDIX D

CORN SILAGE DATA

Year	Method (Center Pivot)	Irrigation (acre-inches)	Rainfall (inches)	Rainfall/ /Irrigation and Soil Water (inches)	Yield (tons/acre)
2009	CP	27.62	5.41	32.76	32.73
2009	CP	27.62	5.41	32.76	32.44
2009	CP	27.62	5.41	32.76	33.55
2009	CP	27.62	5.41	32.76	32.14
2009	CP	27.62	5.41	32.76	33.76
2009	CP	27.62	5.41	32.76	33.27
2009	CP	27.62	5.41	32.76	32.80
2009	CP	27.62	5.41	32.76	34.94
2009	CP	27.62	5.41	32.76	31.61
2009	CP	27.62	5.41	32.76	31.01
2009	CP	27.62	5.41	32.76	33.09
2009	CP	27.62	5.41	32.76	29.47
2009	CP	27.62	5.41	32.76	31.82
2009	CP	27.62	5.41	32.76	33.12
2009	CP	27.62	5.41	32.76	33.09
2009	CP	27.62	5.41	32.76	32.89
2009	CP	27.62	5.41	32.76	33.86
2009	CP	27.62	5.41	32.76	31.49
2009	CP	27.62	5.41	32.76	32.52
2009	CP	27.62	5.41	32.76	33.20
2009	CP	27.62	5.41	32.76	32.66
2009	CP	27.62	5.41	32.76	32.90
2009	CP	27.62	5.41	32.76	32.79
2009	CP	27.62	5.41	32.76	32.21
2009	CP	27.62	5.41	32.76	29.74
2009	CP	27.62	5.41	32.76	32.86
2009	CP	27.62	5.41	32.76	35.83
2009	CP	27.62	5.41	32.76	34.20
2009	CP	27.62	5.41	32.76	29.53
2009	CP	27.62	5.41	32.76	32.57
2009	CP	27.62	5.41	32.76	35.09
2009	CP	27.62	5.41	32.76	31.76
2009	CP	27.62	5.41	32.76	33.52

2009	CP	27.62	5.41	32.76	30.58
2009	CP	27.62	5.41	32.76	31.11
2010	CP	14.58	11.03	25.61	31.09
2010	CP	14.58	11.03	25.61	30.27
2010	CP	14.58	11.03	25.61	28.98
2010	CP	14.58	11.03	25.61	30.74
2010	CP	14.58	11.03	25.61	27.61
2010	CP	14.58	11.03	25.61	29.09
2010	CP	14.58	11.03	25.61	28.70
2010	CP	14.58	11.03	25.61	29.21
2010	CP	14.58	11.03	25.61	28.51
2010	CP	14.58	11.03	25.61	26.90
2010	CP	14.58	11.03	25.61	32.58
2010	CP	14.58	11.03	25.61	29.99
2010	CP	14.58	11.03	25.61	30.45
2010	CP	14.58	11.03	25.61	30.83
2010	CP	14.58	11.03	25.61	33.35
2010	CP	14.58	11.03	25.61	31.66
2010	CP	14.58	11.03	25.61	32.32
2010	CP	14.58	11.03	25.61	31.34
2010	CP	14.58	11.03	25.61	32.12
2010	CP	14.58	11.03	25.61	33.42
2010	CP	14.58	11.03	25.61	28.93
2010	CP	14.58	11.03	25.61	30.90
2010	CP	14.58	11.03	25.61	30.56
2010	CP	14.58	11.03	25.61	32.91
2010	CP	14.58	11.03	25.61	29.52
2010	CP	14.58	11.03	25.61	27.92
2010	CP	14.58	11.03	25.61	30.38
2010	CP	14.58	11.03	25.61	28.26
2011	CP	30.80	2.40	33.20	33.20
2011	CP	30.80	2.40	33.20	35.40
2011	CP	30.80	2.40	33.20	29.60
2011	CP	30.80	2.40	33.20	28.90
2011	CP	30.80	2.40	33.20	31.50
2011	CP	30.80	2.40	33.20	33.20
2011	CP	30.80	2.40	33.20	35.10
2011	CP	30.80	2.40	33.20	35.50
2011	CP	30.80	2.40	33.20	33.90
2011	CP	30.80	2.40	33.20	31.90
2011	CP	30.80	2.40	33.20	30.50
2011	CP	30.80	2.40	33.20	35.00
2011	CP	30.80	2.40	33.20	32.40

2011	CP	30.80	2.40	33.20	34.80
2011	CP	30.80	2.40	33.20	33.40
2011	CP	30.80	2.40	33.20	33.60
2011	CP	30.80	2.40	33.20	32.40
2011	CP	30.80	2.40	33.20	33.10
2011	CP	30.80	2.40	33.20	33.30
2011	CP	30.80	2.40	33.20	32.90
2011	CP	30.80	2.40	33.20	35.10
2011	CP	30.80	2.40	33.20	30.70
2011	CP	30.80	2.40	33.20	33.60
2011	CP	30.80	2.40	33.20	34.80
2011	CP	30.80	2.40	33.20	34.40
2011	CP	30.80	2.40	33.20	36.20
2011	CP	30.80	2.40	33.20	31.00
2011	CP	30.80	2.40	33.20	31.80
2011	CP	30.80	2.40	33.20	28.30
2011	CP	30.80	2.40	33.20	32.80
2011	CP	30.80	2.40	33.20	32.80
2011	CP	30.80	2.40	33.20	33.60
2011	CP	30.80	2.40	33.20	34.40
2011	CP	30.80	2.40	33.20	31.10
2011	CP	30.80	2.40	33.20	34.90
2011	CP	30.80	2.40	33.20	32.10
2011	CP	30.80	2.40	33.20	33.30
2011	CP	30.80	2.40	33.20	35.70
2011	CP	30.80	2.40	33.20	31.80
2011	CP	30.80	2.40	33.20	32.70
2011	CP	30.80	2.40	33.20	33.70
2011	CP	30.80	2.40	33.20	30.90
2011	CP	30.80	2.40	33.20	32.20
2012	CP	25.66	4.41	30.07	31.80
2012	CP	25.66	4.41	30.07	32.30
2012	CP	25.66	4.41	30.07	33.10
2012	CP	25.66	4.41	30.07	34.50
2012	CP	25.66	4.41	30.07	34.50
2012	CP	25.66	4.41	30.07	34.70
2012	CP	25.66	4.41	30.07	31.70
2012	CP	25.66	4.41	30.07	39.70
2012	CP	25.66	4.41	30.07	34.40
2012	CP	25.66	4.41	30.07	33.10
2012	CP	25.66	4.41	30.07	34.70
2012	CP	25.66	4.41	30.07	33.60
2012	CP	25.66	4.41	30.07	33.10

2012	CP	25.66	4.41	30.07	31.30
2012	CP	25.66	4.41	30.07	34.50
2012	CP	25.66	4.41	30.07	33.40
2012	CP	25.66	4.41	30.07	36.40
2012	CP	25.66	4.41	30.07	32.20
2012	CP	25.66	4.41	30.07	35.70
2012	CP	25.66	4.41	30.07	35.00
2012	CP	25.66	4.41	30.07	32.60
2012	CP	25.66	4.41	30.07	39.00
2012	CP	25.66	4.41	30.07	31.50
2012	CP	25.66	4.41	30.07	35.30
2012	CP	25.66	4.41	30.07	33.70
2012	CP	25.66	4.41	30.07	37.30
2012	CP	25.66	4.41	30.07	29.30
2012	CP	25.66	4.41	30.07	31.30
2012	CP	25.66	4.41	30.07	36.70
2012	CP	25.66	4.41	30.07	34.90
2012	CP	25.66	4.41	30.07	35.60
2012	CP	25.66	4.41	30.07	32.30
2012	CP	25.66	4.41	30.07	32.30
2012	CP	25.66	4.41	30.07	33.40
2012	CP	25.66	4.41	30.07	33.30
2012	CP	25.66	4.41	30.07	32.70
2012	CP	25.66	4.41	30.07	27.30
2012	CP	25.66	4.41	30.07	36.40
2012	CP	25.66	4.41	30.07	34.30
2012	CP	25.66	4.41	30.07	31.90
2012	CP	25.66	4.41	30.07	31.70
2012	CP	25.66	4.41	30.07	32.40
2012	CP	25.66	4.41	30.07	32.70
2012	CP	25.66	4.41	30.07	33.70
2012	CP	25.66	4.41	30.07	32.70
2012	CP	25.66	4.41	30.07	35.70
2012	CP	25.66	4.41	30.07	30.00
2012	CP	25.66	4.41	30.07	34.20
2012	CP	25.66	4.41	30.07	32.70
2012	CP	25.66	4.41	30.07	28.30
2013	CP	26.75	5.74	32.49	28.70
2013	CP	26.75	5.74	32.49	30.41
2013	CP	26.75	5.74	32.49	31.76
2013	CP	26.75	5.74	32.49	33.41
2013	CP	26.75	5.74	32.49	31.59
2013	CP	26.75	5.74	32.49	30.55

2013	CP	26.75	5.74	32.49	28.32
2013	CP	26.75	5.74	32.49	31.18
2013	CP	26.75	5.74	32.49	28.89
2013	CP	26.75	5.74	32.49	31.60
2013	CP	26.75	5.74	32.49	27.18
2013	CP	26.75	5.74	32.49	25.79
2013	CP	26.75	5.74	32.49	32.48
2013	CP	26.75	5.74	32.49	31.09
2013	CP	26.75	5.74	32.49	31.35
2013	CP	26.75	5.74	32.49	34.38
2013	CP	26.75	5.74	32.49	29.63
2013	CP	26.75	5.74	32.49	30.57
2013	CP	26.75	5.74	32.49	29.40
2013	CP	26.75	5.74	32.49	31.20
2013	CP	26.75	5.74	32.49	32.57
2013	CP	26.75	5.74	32.49	39.92
2013	CP	26.75	5.74	32.49	32.72
2013	CP	26.75	5.74	32.49	31.80
2013	CP	26.75	5.74	32.49	30.30
2013	CP	26.75	5.74	32.49	35.21
2013	CP	26.75	5.74	32.49	32.77
2013	CP	26.75	5.74	32.49	31.47
2013	CP	26.75	5.74	32.49	31.85
2013	CP	26.75	5.74	32.49	31.14
2013	CP	26.75	5.74	32.49	32.79
2013	CP	26.75	5.74	32.49	32.12
2013	CP	26.75	5.74	32.49	36.32
2013	CP	26.75	5.74	32.49	28.44
2013	CP	26.75	5.74	32.49	28.40
2013	CP	26.75	5.74	32.49	26.95
2013	CP	26.75	5.74	32.49	30.61
2013	CP	26.75	5.74	32.49	29.82
2013	CP	26.75	5.74	32.49	33.45
2013	CP	26.75	5.74	32.49	29.79
2013	CP	26.75	5.74	32.49	26.33
2013	CP	26.75	5.74	32.49	28.77
2013	CP	26.75	5.74	32.49	30.13
2013	CP	26.75	5.74	32.49	30.06
2013	CP	26.75	5.74	32.49	30.92
2013	CP	26.75	5.74	32.49	27.41
2013	CP	26.75	5.74	32.49	25.83
2013	CP	26.75	5.74	32.49	27.21
2013	CP	26.75	5.74	32.49	33.06

APPENDIX E

FORAGE QUALITY OF CORN SILAGE ON MILK PRODUCTION

Year	Estimated lbs. of milk produced per ton of dry matter.	CP	IVTD24	Starch	Lignin
2009	3240	8.3	82.5	45.8	2.4
2009	3239	8.7	82.0	43.5	3.0
2009	3213	8.5	80.5	41.9	3.0
2009	3267	8.0	79.5	40.4	2.8
2009	3213	8.4	80.5	43.2	2.6
2009	3159	7.7	82.0	45.6	2.5
2009	3248	9.1	83.0	43.1	3.0
2009	3271	8.3	83.5	47.7	2.5
2009	3246	8.2	80.0	40.8	2.7
2009	3222	8.7	79.5	37.1	3.1
2009	3217	8.4	83.0	47.9	2.3
2009	3256	8.7	81.5	43.6	3.0
2009	3239	8.4	80.0	37.9	2.9
2009	3324	8.6	82.0	43.9	2.9
2009	3317	8.5	82.5	44.1	2.8
2009	3330	8.3	80.5	38.6	2.5
2009	3273	8.7	79.0	37.0	3.1
2009	3251	8.0	81.0	42.6	2.6
2009	3309	8.3	83.5	47.3	2.7
2009	3269	8.6	83.0	46.8	2.5
2009	3213	8.7	80.5	40.3	2.8
2009	3319	8.3	82.5	45.4	2.5
2009	3138	7.9	80.5	43.4	2.9
2009	3133	7.6	78.5	39.1	2.7
2009	3245	8.3	83.0	47.0	2.7
2009	3211	8.1	80.0	40.7	2.8
2009	3264	8.1	82.0	44.2	2.3
2009	3297	8.5	79.5	38.5	2.8
2009	3120	7.2	78.5	38.7	2.7
2009	3129	8.0	75.5	33.0	3.5
2009	3193	7.7	82.0	46.2	2.7
2009	3201	8.5	82.5	46.3	2.6
2009	3165	7.8	80.5	44.2	2.6
2009	3336	8.1	84.5	48.9	2.5

2009	3331	8.4	85.0	50.7	2.3
2010	3319	8.2	83.0	44.6	3.1
2010	3217	8.6	84.0	49.7	2.4
2010	3344	8.4	83.5	46.9	2.8
2010	3295	8.8	83.0	45.3	3.0
2010	3311	9.5	81.0	39.2	2.9
2010	3195	8.7	79.0	39.0	3.0
2010	3234	9.0	79.0	34.9	2.7
2010	3284	9.3	82.5	42.8	3.0
2010	3313	8.8	81.5	41.1	3.0
2010	3300	8.2	82.5	44.4	2.9
2010	3314	8.1	82.5	44.5	2.3
2010	3302	7.7	83.0	46.8	2.2
2010	3267	7.7	81.0	42.9	2.4
2010	3346	8.5	82.5	44.4	2.5
2010	3036	7.4	79.7	40.5	3.3
2010	3170	7.7	83.7	45.8	3.2
2010	2901	7.3	78.7	42.1	3.2
2010	2805	7.3	77.3	41.8	3.3
2010	2995	8.0	80.0	41.3	3.3
2010	2848	7.2	75.7	37.9	3.5
2010	2639	7.7	73.7	34.0	3.7
2010	3056	8.2	80.0	40.9	3.5
2010	2931	7.4	77.0	34.9	3.7
2010	3118	7.5	81.7	44.5	3.2
2010	2838	7.6	76.0	35.1	3.5
2010	3070	7.6	80.3	40.6	3.2
2010	2964	7.2	77.7	38.3	3.4
2010	3083	7.6	79.7	37.9	3.3
2011	2913	7.5	76.0	35.3	3.6
2011	2934	7.6	77.7	38.2	3.4
2011	3056	7.5	79.0	38.2	3.4
2011	2978	7.3	75.7	37.2	3.4
2011	2743	6.7	75.3	39.6	3.4
2011	2894	7.3	77.3	39.2	3.5
2011	2878	7.6	76.3	35.6	3.5
2011	2921	7.3	75.0	33.8	3.6
2011	2820	7.1	74.7	34.5	3.7
2011	2991	7.5	78.7	41.2	3.3
2011	2964	7.8	77.3	35.0	3.5
2011	2805	7.0	75.7	35.6	3.3
2011	3162	7.9	78.7	34.7	3.7
2011	3129	7.5	79.0	34.5	3.4

2011	2917	7.7	76.7	36.8	3.5
2011	2673	6.8	72.7	33.4	3.5
2011	2896	7.4	77.7	38.5	3.5
2011	3031	7.6	80.7	44.8	3.2
2011	3096	8.0	79.0	35.1	3.6
2011	2799	7.5	74.0	30.2	3.7
2011	2838	7.2	73.7	31.4	3.8
2011	2741	8.3	72.3	27.4	3.8
2011	2595	7.6	69.0	23.9	4.3
2011	2818	7.6	75.0	31.8	3.7
2011	2640	7.9	69.7	22.2	4.6
2011	2896	8.0	75.3	32.4	3.5
2011	2916	8.1	75.0	31.3	3.6
2011	2763	7.7	72.0	26.9	3.9
2011	2831	7.9	73.7	30.1	3.7
2011	2672	7.5	71.7	30.1	3.9
2011	2649	7.0	71.0	27.7	4.2
2011	2670	7.6	71.3	29.1	4.1
2011	2897	7.8	76.3	35.3	3.7
2011	2879	8.1	73.7	25.8	4.2
2011	2751	8.2	73.0	29.1	4.1
2011	3078	7.9	78.3	36.5	3.6
2011	2971	8.5	75.3	25.1	4.1
2011	2955	8.2	75.3	30.6	3.7
2011	3149	9.0	82.3	35.9	3.7
2011	3077	8.6	79.7	32.1	3.4
2011	3027	8.8	79.7	33.3	3.7
2011	2968	8.7	77.3	33.3	3.5
2011	2910	8.6	74.7	29.9	4.1
2012	3023	8.7	78.7	37.4	3.6
2012	2981	9.3	74.3	23.3	4.6
2012	2562	8.9	69.7	18.4	4.8
2012	3025	8.2	80.0	39.4	3.0
2012	2939	8.4	75.7	30.7	3.8
2012	2893	8.3	75.3	30.1	3.9
2012	3143	8.7	79.7	34.9	3.4
2012	3017	8.6	77.0	32.4	3.9
2012	2850	8.7	74.0	27.6	4.1
2012	3075	8.2	78.7	36.2	3.7
2012	2901	7.8	75.7	32.8	3.5
2012	2997	8.6	77.3	32.7	3.4
2012	2977	8.3	78.3	38.5	3.5
2012	2992	8.5	77.3	32.0	3.5

2012	3076	8.4	80.3	37.8	3.5
2012	2833	7.6	75.3	33.2	3.3
2012	3150	9.3	80.3	35.5	3.7
2012	3063	8.5	78.0	32.9	3.4
2012	3024	9.4	78.0	32.5	3.3
2012	3048	8.3	79.7	37.0	3.5
2012	2796	8.0	72.3	25.6	4.1
2012	3130	8.7	79.7	35.4	3.4
2012	3008	8.4	76.7	28.9	3.6
2012	3041	8.8	78.0	33.7	3.2
2012	3005	9.0	78.3	34.0	3.6
2012	3148	9.2	80.3	35.1	3.7
2012	3010	9.0	77.7	30.5	3.7
2012	2946	8.7	76.7	32.5	3.6
2012	2936	8.5	75.0	25.1	3.8
2012	3054	9.1	79.0	34.5	3.6
2012	2947	8.2	75.3	29.6	3.7
2012	2877	8.4	76.3	31.3	3.5
2012	2772	8.0	73.0	26.8	4.0
2012	2973	8.5	76.7	30.5	3.7
2012	2967	9.0	74.3	25.4	3.9
2012	2768	8.3	73.3	28.8	3.9
2012	3065	8.3	81.0	45.0	3.2
2012	3053	9.3	82.3	47.0	3.2
2012	3052	9.4	80.0	42.6	3.5
2012	2886	8.4	76.3	40.0	3.5
2012	3194	9.1	82.7	46.6	3.1
2012	3001	9.3	79.7	42.8	3.4
2012	3059	9.1	81.0	45.4	3.4
2012	2966	9.4	78.0	41.0	3.8
2012	3087	9.4	80.3	42.7	3.4
2012	3079	9.1	82.0	47.0	3.2
2012	2886	9.1	76.3	38.5	3.7
2012	3102	8.5	79.3	36.4	3.9
2012	2977	9.0	78.0	38.8	3.9
2012	2952	9.0	77.3	38.5	3.8
2013	2698	7.9	70.7	28.7	4.3
2013	3069	9.2	80.7	44.3	3.4
2013	2858	8.8	75.3	36.9	3.6
2013	2858	8.6	73.0	32.0	4.0
2013	2909	8.4	78.7	44.5	3.3
2013	2965	8.3	76.7	36.7	3.5
2013	2876	8.7	77.7	41.8	3.4

2013	3110	9.2	83.0	48.5	3.1
2013	3066	8.6	80.0	43.1	3.3
2013	3160	9.5	82.7	47.8	3.1
2013	3053	9.3	76.3	33.5	3.9
2013	2977	9.6	77.3	35.7	4.0
2013	3040	9.8	81.0	42.4	3.7
2013	2990	9.2	77.0	37.6	3.9
2013	2832	7.4	76.3	37.5	3.5
2013	2856	7.2	77.3	37.4	3.3
2013	2901	8.2	77.7	35.8	3.5
2013	2885	7.5	77.7	37.7	3.6
2013	2912	7.9	77.7	39.2	3.6
2013	2894	7.5	77.7	38.5	3.5
2013	2880	7.2	75.3	33.5	3.5
2013	2749	7.6	75.7	37.5	3.7
2013	2867	8.0	76.3	35.6	3.6
2013	2921	7.9	79.3	41.8	3.3
2013	2724	7.6	73.7	32.8	3.8
2013	2618	7.7	72.7	33.8	4.1
2013	2717	7.4	75.0	37.2	3.6
2013	2726	7.8	74.0	33.9	4.0
2013	2754	7.8	73.7	32.2	3.9
2013	2928	7.7	78.0	37.2	3.4
2013	2623	7.6	71.3	30.8	4.0
2013	2797	7.5	75.0	33.7	3.7
2013	2923	7.7	79.0	40.8	3.4
2013	2916	7.3	78.0	39.7	3.5
2013	2715	7.9	73.0	31.1	4.0
2013	2797	7.7	74.0	32.9	3.3
2013	2805	7.9	74.7	33.7	4.0
2013	2812	7.7	76.0	36.4	3.5
2013	2909	7.7	78.7	42.2	3.4
2013	2829	7.6	77.0	39.5	3.3
2013	2721	7.8	75.0	35.6	3.8
2013	2861	7.6	75.3	33.5	3.5
2013	3006	7.8	78.3	36.8	3.5
2013	2689	8.3	70.7	24.9	4.1
2013	2715	7.9	74.7	33.7	4.0
2013	2707	7.8	74.0	32.6	3.8
2013	2854	7.1	74.0	30.3	3.9
2013	2782	7.8	74.7	34.3	3.6
2013	2936	7.8	76.3	33.6	3.6

APPENDIX F

FORAGE QUALITY OF SORGHUM SILAGE ON MILK PRODUCTION

Year	Estimated lbs. of milk produced per ton of dry matter.	CP	IVTD48	Starch	Lignin
2007	1988	5.9	68.0	11.0	5.3
2007	2182	7.1	71.3	15.7	4.6
2007	2494	6.4	76.7	15.7	3.4
2007	2497	6.3	78.0	18.4	3.0
2007	2022	5.6	68.3	17.3	5.6
2007	2201	6.8	70.7	13.8	5.0
2007	2131	6.6	71.0	16.4	5.3
2007	2856	8.2	80.3	5.0	2.8
2007	2908	8.7	81.0	14.1	3.2
2007	2524	7.8	74.7	13.5	4.7
2007	2590	8.7	76.0	10.0	3.5
2007	2807	7.9	80.0	11.2	2.8
2007	2925	9.1	80.0	21.9	3.2
2007	2527	7.2	75.3	12.7	4.7
2007	2548	6.2	75.3	12.7	3.5
2007	2711	8.4	78.7	16.8	2.8
2007	3036	7.6	83.3	9.1	3.8
2007	2620	7.9	78.0	9.0	4.0
2007	2639	7.1	79.0	17.7	4.1
2007	2590	7.1	78.7	15.2	4.0
2007	2894	7.1	81.3	32.2	2.8
2007	2294	5.8	72.7	18.0	4.4
2007	2518	7.2	75.3	18.2	3.0
2007	2831	7.3	81.3	22.6	4.1
2007	2572	7.4	76.5	14.1	4.5
2007	2608	7.2	77.7	10.9	4.0
2007	2745	6.8	78.0	14.5	3.6
2007	3235	9.6	83.7	3.2	5.0
2007	2720	8.1	76.0	22.9	4.1
2007	2428	8.0	73.3	20.8	3.5
2007	2529	8.1	75.7	23.1	3.1
2007	2981	7.6	81.7	18.5	4.3

2007	2730	7.3	80.0	23.4	4.6
2007	2729	8.5	78.3	10.3	5.1
2007	2942	8.9	82.3	8.1	3.5
2007	2402	5.8	73.3	12.4	3.9
2007	2919	7.1	81.0	9.6	4.0
2007	2934	7.7	81.3	10.0	2.3
2007	3184	8.2	84.0	15.0	4.8
2007	2883	8.0	81.3	13.5	3.4
2008	2930	9.2	80.0	17.4	3.1
2008	2705	7.6	81.0	16.6	3.4
2008	2975	8.2	83.3	18.3	3.0
2008	2696	9.3	80.0	15.4	3.4
2008	2831	7.7	85.7	18.3	3.5
2008	3174	8.7	73.7	15.0	1.5
2008	2442	7.6	78.3	19.2	5.1
2008	2593	8.1	85.0	13.7	3.3
2008	3130	8.2	75.7	21.5	2.9
2008	2506	7.2	78.0	19.3	4.4
2008	2605	7.0	83.7	18.4	4.0
2008	2978	8.7	80.7	17.4	2.8
2008	2740	7.5	79.3	18.5	3.5
2008	2707	8.2	83.7	17.0	3.7
2008	2963	7.8	80.7	15.7	2.6
2008	2394	6.5	79.3	15.7	2.4
2008	2646	6.5	83.7	18.4	2.9
2008	3070	8.6	80.7	17.3	4.7
2008	2622	8.6	79.3	13.8	2.6
2008	3152	8.8	83.7	16.4	5.3
2008	2280	5.2	74.7	5.0	3.1
2008	2921	7.3	77.0	16.1	2.4
2008	2297	6.6	84.0	19.3	4.8
2008	2819	8.4	79.7	18.7	3.7
2008	2965	8.2	85.7	19.8	4.3
2008	2359	7.2	73.0	19.4	4.4
2008	2566	6.1	82.7	19.3	3.9
2008	2443	7.5	71.7	10.3	2.4
2008	2247	7.0	80.0	5.5	4.5
2008	2728	8.8	83.7	18.2	3.2
2008	3275	9.1	73.0	22.6	2.6
2008	2336	5.8	70.0	14.1	3.2
2008	2772	5.5	76.3	10.9	3.9
2008	2938	7.0	73.3	14.5	3.5
2008	2532	5.5	78.0	3.2	3.0

2008	2701	7.9	85.3	22.9	2.9
2008	2935	9.3	74.0	20.8	3.1
2008	2701	10.2	80.7	23.1	4.9
2008	2935	9.1	83.0	18.5	2.6
2008	3033	9.6	78.3	23.4	3.7
2009	2650	9.1	80.7	10.3	3.8
2009	2515	6.8	80.3	8.1	3.7
2009	2917	7.6	82.0	12.0	3.3
2009	2652	9.4	80.0	14.1	3.7
2009	2564	8.1	76.3	13.5	4.5
2009	2516	8.7	77.0	10.0	4.6
2009	3028	7.8	83.7	11.2	2.5
2009	3004	8.2	80.7	21.9	3.3
2009	2574	7.5	76.7	12.7	4.3
2009	2197	6.4	73.3	12.7	4.9
2009	2926	9.0	84.0	16.8	3.1
2009	2435	6.5	79.3	9.1	4.3
2009	2878	8.6	84.0	9.0	2.8
2009	2834	9.4	79.3	17.7	3.7
2009	2182	6.0	84.0	15.2	5.4
2009	3162	9.7	82.3	32.2	3.2
2009	2922	7.0	72.3	18.0	3.1
2009	2762	8.2	83.3	18.8	4.3
2009	2503	5.6	82.0	7.9	3.7
2009	2859	7.2	79.0	16.6	3.3
2009	2469	5.8	77.3	3.70	3.1
2009	2322	6.4	82.0	11.0	1.9
2009	2928	8.0	77.1	21.6	3.4
2009	2771	8.0	75.3	17.0	3.9
2009	3252	9.8	82.3	18.8	2.2
2009	3286	8.2	81.0	19.0	4.0
2009	2493	6.9	85.7	4.8	4.7
2009	2404	4.7	86.7	8.7	4.6
2009	2448	8.7	77.7	6.6	3.4
2009	2954	7.3	75.7	19.2	2.9
2009	3055	8.3	81.7	19.5	2.9
2009	3035	9.2	83.0	14.6	5.1
2009	2287	6.6	83.0	13.5	3.5
2009	3025	8.0	74.3	19.2	5.5
2009	2022	4.6	82.7	5.5	4.4
2009	2216	6.6	69.7	4.8	3.8
2009	2718	7.9	73.7	4.1	4.5
2009	2183	5.2	77.0	10.7	3.5

2009	2097	7.3	75.3	13.6	4.0
2009	2449	8.5	81.0	16.8	5.1
2010	2638	7.6	76.7	19.6	4.2
2010	3049	8.9	82.3	19.1	3.2
2010	3046	9.3	82.7	10.4	2.4
2010	2980	8.7	82.3	20.8	3.2
2010	2628	7.2	78.3	10.1	3.5
2010	3323	8.4	85.7	18.4	2.2
2010	2908	8.2	82.0	17.5	2.8
2010	2704	8.4	79.7	17.8	3.8
2010	3195	8.3	84.7	11.6	2.6
2010	2916	8.6	81.7	21.1	3.3
2010	2760	8.8	79.7	15.7	4.0
2010	2274	7.5	73.7	15.7	5.1
2010	2876	8.2	81.0	27.4	3.6
2010	2819	7.8	80.0	15.9	3.0
2010	3116	8.5	83.3	21.0	3.2
2010	2850	7.8	81.3	19.0	3.3
2010	2691	7.1	76.3	19.7	4.6
2010	2759	7.9	77.3	18.2	4.2
2010	2875	9.5	80.7	22.9	3.6
2010	2465	5.7	73.7	18.3	4.8
2010	3113	7.8	84.7	12.0	1.8
2010	2759	5.4	78.0	12.5	3.4
2010	3005	8.2	82.3	16.2	2.9
2010	2641	7.2	77.7	5.13	3.7
2010	2739	8.0	79.0	18.0	3.7
2010	2711	6.4	81.3	19.0	4.2
2010	2973	5.7	77.7	21.7	3.5
2010	2632	8.4	76.3	5.4	3.3
2010	2645	9.1	86.0	14.2	2.2
2010	3160	6.1	85.3	15.1	2.1
2010	3296	6.8	77.0	18.7	3.5
2010	2588	9.6	77.0	5.63	4.2
2010	2525	8.1	83.0	11.6	3.1
2010	3083	8.0	81.3	23.8	3.4
2010	2941	7.4	81.3	20.8	2.9
2010	2968	8.7	83.7	17.9	2.2
2010	3164	8.5	79.7	24.3	3.8
2010	2875	6.3	80.3	20.8	3.7
2010	2745	5.8	76.7	17.9	3.6
2010	2707	7.5	74.7	24.3	4.1
2011	1980	7.3	73.1	9.1	4.5

2011	1903	8.4	73.2	14.8	4.4
2011	2045	8.0	73.8	11.4	4.7
2011	1985	6.7	74.7	8.2	4.3
2011	2169	7.5	74.7	5.0	3.7
2011	1850	8.1	72.2	6.2	4.5
2011	1790	6.9	66.7	13.0	5.0
2011	1382	5.2	67.7	5.1	5.3
2011	1913	8.4	70.8	6.9	4.3
2011	1651	7.6	75.6	14.1	4.1
2011	2132	6.7	69.9	7.7	4.4
2011	1913	6.6	68.1	1.7	4.9
2011	1651	5.6	70.7	12.7	5.1
2011	2132	5.0	70.5	9.8	4.7
2011	1733	7.1	71.7	7.1	4.5
2011	1906	6.9	72.8	10.3	4.7
2011	1399	7.9	73.0	16.9	4.3
2011	2071	7.4	74.1	8.2	4.1
2011	1753	8.0	72.4	5.2	4.2
2011	2286	8.1	76.2	14.2	4.2
2011	2250	7.0	68.6	12.0	5.0
2011	2056	9.6	77.0	25.6	4.1
2011	1958	5.8	68.7	2.4	5.1
2011	2061	6.5	68.2	2.6	5.3
2011	2414	5.1	67.5	2.4	4.8
2011	1740	5.9	67.5	4.7	4.9
2011	1600	8.5	72.1	12.8	4.4
2011	2024	7.9	74.8	23.3	4.2
2011	1625	6.8	75.1	15.4	3.9
2011	2088	9.3	70.5	11.8	4.2
2011	1952	7.7	72.2	24.6	4.6
2011	2483	5.5	69.5	18.2	5.1
2011	2150	7.0	70.6	2.2	4.0
2011	1766	5.1	73.0	16.6	4.3
2011	1814	5.2	67.3	1.6	4.5
2011	2031	6.5	66.4	1.7	4.8
2011	1838	8.1	71.2	2.9	4.4
2011	1921	6.7	72.7	26.2	4.7
2011	1730	7.9	67.7	8.6	5.1
2011	2093	8.8	73.6	14.2	4.0
2014	3554	8.2	79.9	26.4	5.2
2014	3220	8.2	81.7	30.5	5.0
2014	2948	7.9	84.1	33.3	4.7
2014	3051	8.1	79.4	17.9	4.2

2014	3239	9.5	81.1	29.8	5.5
2014	2767	8.0	79.4	18.3	5.6
2014	2978	7.5	81.1	10.4	4.0
2014	2629	8.6	78.9	15.1	4.4
2014	2423	7.2	77.6	8.7	5.5
2014	2644	7.6	80.1	22.7	5.7
2014	2698	7.3	71.4	20.0	4.8
2014	2858	7.5	77.5	24.2	6.2
2014	2844	7.3	80.1	25.8	5.8
2014	2106	8.5	71.4	22.6	7.7
2014	2748	7.1	77.5	16.5	5.3
2014	2281	8.7	80.4	21.1	5.6
2014	2853	5.9	79.1	13.3	8.9
2014	2895	7.4	79.8	18.2	9.7
2014	2895	7.8	72.6	16.7	9.8
2014	1953	7.3	77.3	15.1	4.5
2014	2100	8.2	79.4	13.2	5.2
2014	2096	7.0	67.0	19.9	5.8
2014	2436	6.6	69.3	2.0	5.8
2014	2526	7.1	69.6	19.7	7.0
2014	2430	6.1	76.8	1.5	7.1
2014	1856	7.2	77.8	2.6	6.6
2014	2408	6.8	75.6	8.1	6.2
2014	1618	9.7	70.9	22.9	5.8
2014	1900	7.5	73.3	29.3	4.9
2014	2006	9.6	64.8	23.1	6.7
2014	2711	7.1	67.3	9.9	6.4
2014	3104	8.9	69.7	20.5	5.1
2014	2661	8.1	79.3	21.3	5.7
2014	2237	7.3	81.0	19.8	4.5
2014	3022	8.9	77.3	31.5	6.5
2014	3241	8.6	71.3	31.9	4.0
2014	2900	8.1	79.2	25.4	4.1
2014	2766	7.7	79.0	33.9	4.4
2014	3131	8.1	80.6	17.0	4.4
2014	3262	7.7	77.7	24.9	4.8