CATTLE GRAZING AND PROFITABILITY IN A DRYLAND WHEAT-SORGHUM-FALLOW ROTATION WITH AN EL NINO - LA NINA DECISION VARIABLE

By

Noah Paul Jesko, B.S.

A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

Major Subject: Agriculture

Emphasis: Agricultural Business and Economics

West Texas A&M University

Canyon, Texas

August 2019

Approved by:

Dr. Mallory Vestal — Date
Chairman, Thesis Committee

Dr. David Lust — Date
Member, Thesis Committee

Dr. Louis Baumhardt — Date
Member, Thesis Committee

Dr. Bridget Guerrero — Date
Member, Thesis Committee

Dr. Lance Keith — Date
Department Head, Agricultural Sciences

Dr. Kevin Pond — Date
Dean, Paul Engler College of Agriculture and Natural Sciences

Dr. Angela Spaulding — Date
Dean, Graduate School

ABSTRACT

The gradual decline of the Ogallala Aquifer has partially led to an overall decrease in the number of irrigated acres within the Texas High Plains. With the decline of sub surface water resources, producers are looking to alternative enterprises such as dryland production systems. A common dryland production system is the wheat-sorghum-fallow (WSF) rotation. This system can also be varied to include livestock grazing. The two primary objectives within this study are (i) evaluate the profitability of the WSF production system when coupled with alternative cattle grazing systems, and (ii) provide an analysis of the profitability of incorporating El Nino - La Nina predictive information as a decision variable with the grazing decision. From 1999-2009, WSF rotational phases were established in duplicate ungrazed and grazed plots in three replicated paddocks in Bushland, Texas. A target stocking rate of 725 kilograms per hectare was established, which yielded an approximate 0.38 head per hectare. Average monthly cattle prices were generated by compiling and averaging sale data from 2015-2017 for the Amarillo, Dalhart, and Tulia Livestock Auctions. Results indicate that when comparing contracting versus owning cattle on the WSF system, the most profitable is to own the cattle that are grazing, though it was less risky to contract them. The El Nino -La Nina decision variable assumed grazing in El Nino years and no grazing in La Nina years. Overall, yields in sorghum and wheat were not found to be statistically different

between the grazing and non-grazing years. A significant difference was not found in the profitability between the grazing and non-grazing years. The difference in profitability between using the decision variable and not using the decision variable was numerically different, with the estimated profit per hectare being $492.69 per hectare for contact grazing and $489.74 per hectare for owned grazing.

Keywords: *beef cattle, crop rotation, dryland, grazing, wheat-sorghum-fallow rotation*

ACKNOWLEDGEMENTS

Dr. Vestal, thank you for being the driving force behind me entering the Master's Program. Your help and your knowledge have been amazing to have in my corner.

Dr. Lust, thank you for giving me a job and for allowing me to do both it and work for Dr. Vestal. You have taught me a great deal, and I look forward to continuing that trend.

Dr. Baumhardt, thank you for allowing me to use your research. Though I will never do as good a job as you I appreciate your letting me try. It is men like you that have and will continue to push the boundaries of research.

The Nance Crew, thank you all for always picking up my slack when I needed to spend time working on this paper. It was and always will be greatly appreciated.

This research was funded by a Graduate Research Award from the Ogallala Aquifer Project and Ogallala Water CAP.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - INTRODUCTION

Irrigated land in the Texas High Plains has decreased by 1,358,500 acres or 549,765 hectares from 1974 to 2000, in large part due to the declining Ogallala Aquifer, which supplies irrigation water to the area (Colaizzi et al., 2009). With an increase in pumping costs and declining well capacities, producers in the U.S. Southern High Plains have incorporated dryland cropping systems into their operations (Baumhardt and Salinas-Garcia, 2006). One common practice within dryland production is the three-year wheat, grain sorghum, fallow rotation (WSF). The WSF rotation begins during September of year one with the planting of winter wheat on all or part of the rotation, which is subsequently harvested for grain in July (Figure 1). The land is then fallowed for eleven months until June of year two when grain sorghum is planted and then harvested in November. Following harvest of grain sorghum, the land is fallowed through the next summer cropping season when wheat is planted. This rotational system uses the soil water stored during fallow phases alongside seasonal precipitation to consistently produce two dryland crops in a 3-year cycle. On average, mean grain yields are 1,200 kilograms per hectare for wheat and 3,098 kilograms per hectare for sorghum (Jones and Popham, 1997). As producers look to enhance the revenue generation of the WSF system, one common alternative is to include cattle grazing. For example, Decker et al. (2009)

found that grazing wheat grown for forage or dual-purpose forage and grain production increased profitability over the corresponding grain-only system. This was with both conventional tillage and no till planting systems, and for both a 260-hectare farm and a 1,036-hectare farm (Decker et al., 2009).

Within the WSF system, producers often manage multiple fields. As such, all three phases will appear in any one year. This practice facilitates the grazing of growing wheat and sorghum stover simultaneously (Baumhardt et al., 2009). Grazing can be incorporated on the wheat forage and nearby sorghum stover during all or part of a period from November to March (Baumhardt et al., 2006; Baumhardt et al., 2009). This grazing occurs during the dormant wheat period, and cattle are removed before the crops jointing stage when the leafy plant begins to develop a stem and grain. Wheat pasture and the nearby sorghum stover can supply high quality forage capable of meeting protein, energy, and fiber demand for grazing cattle (Dhuyvetter et al., 1996).

The addition of cattle grazing allows the opportunity for increased productivity of the operation and subsequent profitability. Furthermore, producers have the option to own the cattle or to lease the forage to another producer for grazing. The profitability of this production system is largely dependent upon rainfall. In years with adequate rainfall, the additional livestock grazing can be beneficial, while in years of lower precipitation, the additional grazing can be too intense and have a negative impact on the system.

While producers do not have the ability to forecast annual rainfall, they do have an expectation or prediction variable. The El Nino is the warm phase of the El Nino-Southern Oscillation (ENSO) and is associated with a band of warm ocean water that begins in the central equatorial Pacific. It is accompanied by high air pressure in the

Western Pacific and low air pressure in the Eastern Pacific. In El Nino years, the Southern United States receives more rainfall than average (Mauget and Upchurch, 1999). La Nina episodes represent periods of below-average sea surface temperatures across the east-central Equatorial Pacific. Global climate La Nina impacts tend to be opposite those of El Nino impacts. In the tropics, ocean temperature variations in La Nina also tend to be opposite those of El Nino. During a La Nina year, winter temperatures are warmer than normal in the Southeast and cooler than normal in the Northwest (CPC, 2015).

Producers can utilize this variable as an aid in the decision of when cattle grazing should and should not be incorporated into the WSF rotation system. Profits from dryland agriculture in semiarid regions are strongly tied to rainfall, knowledge of growing season precipitation before planting could allow producers to make managerial decisions that help negate risk (Mauget, Zhang, and Jonghan, 2009). As producers move to more dryland systems, these WSF rotational systems merit economic evaluation. The objectives of the study were to;

- Provide an analysis of the profitability of the dryland WSF rotation when coupled with cattle grazing in the Southern High Plains.
- Evaluate the profitability of alternative cattle ownership specifications.
- Provide an analysis of the profitability of incorporating El Nino - La Nina predictive information as a decision variable within the grazing decision

CHAPTER 2 - LITERATURE REVIEW

In 2017, the USDA reported 1,675,000 acres of wheat planted in the Northern High Plains of Texas, and about half of those acres were harvested (Mann Library, 2017 and USDA - NSS, 2017). The harvest production led to approximately $318 million dollars of value. In 2018, the Texas Farm Bureau (Walker, 2018) estimated that throughout the state of Texas over two million acres of sorghum [Sorghum bicolor (L.) Moench] would be grown. Though the value of production for both crops, specifically wheat (Triticum aestivum L.), is high, producers face a level of inherent risk if they dedicate all acres into one enterprise. In an effort to minimize the risk, producers incorporate multiple crop enterprises into their operation. Producers can also stock cattle on their wheat (pre-harvest) and their sorghum stover (post-harvest) to supplement the production system. This is where producers turn to the wheat-sorghum-fallow (WSF) rotation.

The production of wheat in the Texas High Plains is an essential aspect of many producer's management techniques. The primary wheat grown in the WSF rotation in the Texas High Plains is hard red winter wheat. In this region wheat, can be planted as early as September 1 to maximize fall forage, or as late as October 20 for grain production (Epplin, Hossain, and Krenzer, 2000). Fall forage is typically maximized when wheat is planted in early September and production steadily declines as wheat is planted later in the season (Decker et al., 2009). The Texas A&M AgriLife Extension, (Amosson, 2015; 2016; 2017) estimated that producers who plant and harvest wheat could expect a return above specified costs of $10.16 per acre, considering a $4.20 per bushel wheat price. This is one of the reasons producers in the Great Plains use a wheat-fallow (WF) cropping system. However, with the WF System, only one crop is produced every two years (Baumhardt and Anderson, 2006). When wheat is grown in a rotational system with grain sorghum, a producer can produce two crops in three years. Williams et al. (2010) found the WSF rotation to produce more income than the stand-alone WF system. Under the Agricultural Act of 2014, (Lucas, 2013) farmers can plant sorghum and still receive deficiency payments on their wheat acres. Dhuyvetter et a. (1993), show that if government deficiency payments were not available, the WF systems would not be profitable in the Texas High Plains. He goes on to show it is more productive in Northern Colorado and Kansas. The Texas A&M AgriLife Extension Service (Amosson, 2015; 2016; 2017) estimated that producers who incorporated the WSF rotational System could expect return above specified costs of $12.60 an acre (2015-2017 average). This has led many producers in the area to move away from the traditional WF system and begin using the WSF rotation.

In the Texas High Plains, there are two major types of tillage used in wheat production: conventional till and no till. Various arguments have been made on behalf of each practice, however the foremost argument against conventional tillage is the reduction in soil water retention. The advent of the no-till system greatly improved our ability to capture and retain precipitation in the soil during the non-crop periods of the cropping cycle (Peterson et al., 1998). In the Great Plains, the no till system consistently has higher volumetric water content in the 0 – 1.2-meter depth (Dao, 1993). In fact, the WSF rotation is even more profitable with no-till than with conventional till (Peterson et al., 1998) and has caused many producers to move to a no till practice. Decker et al. (2009) showed that each practice has different benefits depending on the type of wheat production the producer is looking to maximize. In research conducted in the Southern Plains of the United States, five alternative wheat production systems were observed over a three-year period. Results indicated wheat grain yields were 16% greater within a ploughed system compared to a no till system (Decker et al., 2009). This is consistent with Raney and Zingg, (1957) though they write that the amount of stubble left in the field should determine the tillage system. Decker et al. (2009) continue to indicate that larger amount of residue coupled with no till (NT) and smaller amounts of tillage with conventional till (CT) lead to greater yields. Though the reason is unknown, it is most likely attributed to a higher likelihood of disease on the wheat straws that are left when no till is used. For producers who are interested in high grain yields, the plough system is the most beneficial. Wheat fall forage production was higher in the no till system than in the ploughed system. For producers who wish to graze cattle, the no till system typically leads to higher returns (Decker et al., 2009)

Another important aspect of the wheat-sorghum-fallow rotation is the availability, or lack thereof, of water to irrigate. In the areas of the Texas High Plains where hard red winter wheat is typically grown, nearly all the irrigation used is pumped from the Ogallala Aquifer. Over 90% of all withdrawals from the aquifer in the Texas High Plains is for irrigation (Colaizzi et al., 2009). The Ogallala is a closed basin and current withdrawals greatly exceeded the rate of recharge. Due to the large levels of withdrawal, a rapid decline in groundwater levels has resulted. In some areas, more than 50% of the predevelopment saturated thickness has been pumped, and groundwater levels have dropped over 50 meters (McGuire, 2017). Though this information is daunting, Almas, Colette and Taylor (2007) estimated that a change from irrigated land to dryland cropping systems would have severe economic consequences. The change from irrigated production to dryland reduces the groundwater withdrawal, however it also reduces the profitability of the formerly irrigated production system. When faced with lower yields on dryland WSF rotations, producers can incorporate grazing in an effort to enhance the profitability of the operation (Almas et al., 2007).

The introduction of cattle grazing on the WSF rotation can allow producers to significantly increase the intensity with which they use the system. The grazing of wheat has had a significant impact on the utilization of the plant in the Texas High Plains as a dual-purpose crop. The main type of cattle grazed on winter wheat in the High Plains are stocker cattle. Stocker cattle are often bought in the fall and placed on wheat pasture with the intent of selling to feedlots in the spring. The producers who incorporate stocker cattle grazing plan on receiving profit on the pounds gained by the calves as they are grazing the wheat pasture. There are two ways that producers can incorporate this "per pound gain" profit. First, they can own the cattle outright, or secondly, they can lease out their wheat pasture to another producer. In a study done by Harrison et al. (1996), it was found that contract grazing significantly reduces risks for pasture owners, but not for cattle owners. However, Anderson et al. (2004) found that higher returns result in direct ownership as opposed to contract options. Furthermore, on average, the break-even grazing fee for the cattle owner was higher than the caretaker's break-even fee. This indicated the potential for both parties to profit from contract agreements. The idea of contracting cattle onto wheat pasture could potentially be beneficial for many High Plains producers. The contracts could help producers negate risk involved with stocker cattle to still receive an income which is semi regular, while they do not have to expend as much capital. Contracting land for the cattle owner gives them the opportunity to increase their cattle investment while not having to worry about land management or acreage constraints (Anderson et al., 2004). The winter wheat pasture is a unique and renewable resource which has great economic benefits. Wheat pasture income is derived from both grain and the increased value that is added, as weight gain, to growing cattle grazed on wheat pasture (Horn et al., 2005). The probability for profit on grazed wheat is very high because of the high-quality feed and the seasonality of cattle prices that favor price appreciation (Horn et al., 2005).

The cattle industry makes very little use of contracts, with only an estimated 10% of cattle being produced under contract. While in the poultry industry, an estimated 90% of total marketing and production takes place under contracts. As with hedging, contracts provide an avenue for producers and buyers to both reduce risk in the market and potentially capture profit at the same time (Bechtel, 2019). Bechtel, (2009) continues to estimate that the average U.S. cow-calf operation tends to be profitable only six years in each twelve-year period. While on the other hand, contract grazing is profitable in every defined scenario (Bechtel, 2019). Teegerstrom et al. (1997) indicated that cow-calf systems are the preferable systems when looking at a maximum dollar amount that can be achieved. In every other scenario contract grazing is the optimal alternative, this is especially the case in for their maximum of minimum criteria. This criterion shows that of all the minimum returns, contract grazing had the highest floor (Teegerstrom et al., 1997).

One of the main issues producers encounter when grazing wheat is determining the correct stocking rate. The amount of forage available is determined by a plethora of factors, including plant date, rainfall, and temperature. Of the factors tied to forage, planting date is the only one that is partially controlled by the producer, though, even that, depends on other factors out of their control. The stocking rate, on the other hand, is completely controlled by the producer and is possibly the most important variable. Developing and maintaining a profitable level of gain is vital to a producer's survival. Redmon et al. (1996) stated that herbage intake and animal performance would increase with increased herbage allowance, but plateau at an herbage allowance of about 10 to 12 percent body weight. In conjecture with this, daily intake of stocker calves decreased when herbage allowance was reduced to 30 kg dry matter (DM) per 100 kg body weight (BW) or lower. This is particularly important for producers as overstocking could cut into the per pound gain per animal and affect profit. It is also important for producers to understand the possible need for supplementation of stocker cattle during their time on wheat pasture. The two main types of supplement for cattle on wheat deal with controlling bloat occurrence and increasing energy amounts. Research indicates that wheat forage contains marginal to enough phosphorus (P) and magnesium (Mg), excess potassium (K), and inadequate amounts of calcium (Ca) (Horn et al., 2005) In most cases, Ca is the primary concern when stockers on are on wheat cattle, because a lack of Ca has the most detrimental effect on growing cattle. However, the supplemental Ca could also help to hinder frothy bloat by increasing rumen motility. Supplementing stocker cattle with an energy supplement was shown to increase average daily gain (ADG) by an average of 0.15 kg/day with high starch and high fiber supplements (Horn et al., 2005). Feeding high energy supplements to cattle that are growing on wheat is a way for producers to improve the predictability of their calf performance and weight gain (Horn et al., 2005).

Another issue that occurs when cattle are grazing wheat pasture is the occurrence of frothy bloat. This is a result of complex interactions between many different factors including plant, animal, and the environment (Min et al., 2005). The animal factors contributing to frothy bloat are ruminal gas and foam production, passage rate of feed, and microbe densities. The rapid release of soluble protein into ruminal fluid promotes the formation of the polysaccharide slide that leads to frothy bloat (Clarke and Reid, 1974). The frequency of bloat can be controlled by the amount of forage available to the cattle. Forage allowance has a profound effect on bloat dynamics within and among vegetative growth (January – February) stages of wheat (Clark and Reid, 1974). In their study Horn et al. (2005) found average bloat scores were 4.0 to 2.5 times greater in steers grazing at a high forage allowance than at a low forage allowance in the vegetative and reproductive growth (March – April) stages of wheat, respectively. Though there was no previous research correlating the two, it is shown that having a higher stocking rate can help reduce instances of bloat. For producers, this adds another variable which must be factored into the decision-making process. As stocking rate increases, bloat tendencies decrease, however, if the wheat becomes overstocked then ADG can be negatively affected. The intake rate of each animal, which is the outcome of stocking rate, correlates directly to both ADG and bloat instances. Just as bloat tendency can be controlled by forage allowance, the incorporation of certain minerals may also have a positive effect on the frequency with which bloat occurs. For instance, a free choice mineral containing 150 mg of lasalocid/113.4 g mineral was found to decrease bloat frequency and severity (McDuffey, Richardson, and Wilkinson, 2001). Producers must factor in the stocking rate with which they believe the best ADG will be attained, while also factoring in the effect that stocking rate has on bloat frequency as well as the correct mineral composition to help aid in ADG and in reduction of bloat (Horn et al., 2005).

Grazing of sorghum and corn stalks is a commonly used source of winter feed. Issues that producers face with these winter feeds, particularly with stocker cattle, is the lack of significant gain in the cattle. As a result, producers often must supplement their calves with protein tubs or cubes. The grazing of wheat in conjecture with sorghum has numerous benefits a producer can capitalize when done correctly. The ideal scenario, if acreage allows, would be to have one of each portion of the rotation in production simultaneously. For instance, a producer with three adjacent pastures would have one planted into wheat, one as sorghum stover, and the final as fallow. The producer would then follow the WSF rotation and move among the different rotations so that cattle would have the opportunity to graze both sorghum stover and wheat at the same time. This mixed system has advantages others do not, such as weed control, higher nutrient recycling, and a diversified income. The largest disadvantages include the requirement of more livestock expertise, capital, and the risk of additional soil compaction.

The El Nino Southern Oscillation Cycle (ENSO) is a climate phenomenon that periodically moves between three phases: Neutral, El Nino, and La Nina. The El Nino and La Nina phases are opposites. El Nino years are related to an increase in the temperature of the eastern Pacific Ocean as well as high air pressure. The La Nina years are related to a decrease in the temperature of the Pacific and have lower air pressures. These periods usually last several months, and their intensity can fluctuate. The incorporation of an El Nino - La Nina decision variable could help farmers negate risk and increase profitability by helping with the grazing decision. When wheat is planted and an El Nino year is predicted, producers could benefit from grazing their wheat or leasing their wheat out to other cattle producers. If a La Nina year is predicted, the producers would simply refrain from grazing the wheat. These decisions help the producers decide on the basis that El Nino years typically bring more rainfall to the Southern High Plains than do the La Nina years. Typically, most areas in the United States receive over 50% of their rainfall in fewer than 20% of the rain days (Gershunov and Barnett, 1998). Most of the rainfall in the Southern High Plains occurs from May to August (CPC, 2015) thus, the prediction of El Nino years could significantly boost a producer's profit. El Nino years typically bring wetter and cooler than normal winter seasons (CPC, 2015), which means that extra rainfall is predicted when a typical year would have smaller amounts. The ENSO mature phase, when rainfall is most expected in the Texas High Plains, occurs at just the same time as the dormant phase in hard red winter wheat, which is December through February (Mauget, Zhang, and Jonghan, 2009). In the Gulf Coast and the Texas Panhandle, the frequency of heavy rainfall events is enhanced by 15% to 30% during El Nino years (Gershunov and Barnett, 1998). Larger amounts of rainfall increase the likelihood that dual purpose wheat can thrive both as a cattle grower, and as a grain to be harvested. More rainfall will lead to greater grain yields, even when cattle are grazed before harvest. The predicted dry spells of La Nina years would lend to a lesser chance of enough yields if the wheat plants were stressed by cattle grazing.

The previous literature indicates many different factors that contribute to the overall productivity of the WSF rotation. Conventional and no till systems were both found to be successful depending on the outcome producers seek. Peterson et al. (1998) indicated that the no till system was more profitable when using the WSF rotation. Though Decker et al. (2009) stated that conventional tillage led to 16% higher wheat yields. The incorporation of cattle was also found to boost the WSF system productivity (Decker et al., 2009), yet this leads to factors associated with bloat and stocking rate. Horn et al. (2005) found higher bloat occurrence when stocking rates allowed for higher forage allowances per animal, indicating that higher stocking rates decrease bloat and increase production. The El Nino - La Nina seasonality was found to have a large impact on the Texas High Plains, especially the growing of hard red winter wheat. Mauget, Zhang, and Jonghan, (2009) indicate that El Nino years should have a positive impact on wheat production as rainfall should increase during the wheat’s dormant phase, allowing soil moisture accumulation prior to the spring growing season. An economic analysis over all factors contributing to the profitability of the WSF rotation, looking at grazing, ownership and ENSO factors is warranted.

CHAPTER 3 - MATERIALS AND METHODS

Primary Objective

The primary objective of this study is to determine the profitability of the WSF rotation when cattle grazing is incorporated. The study is expanded by examining system outcomes based on ownership of cattle as opposed to contract grazing. A contract based on pounds gained could be beneficial for both the owner of the cattle and the owner of the land, however this should be compared to the results of direct cattle ownership. Additional examination to determine if a grazing decision variable based on El Nino - La Nina predictions can impact profits on a grazed WSF rotation.

Experimental Design

From 1999-2009, all WSF rotation phases were established in duplicate ungrazed and grazed plots in three replicated paddocks on a gently sloping Pullman silty clay loam at the United States Department of Agriculture – Agriculture Research Service, Conservation and Production Research Laboratory in Bushland, Texas. Blocks were randomly assigned to each of the three phases of the WSF rotation. Each block contained randomly assigned grazed or ungrazed treatments in two 165-m wide paddocks. Paddocks were divided into three, 55-m wide plots that were assigned one of three phases of the WSF rotation (Jones and Popham, 1997) so that all wheat, sorghum, or fallow rotation phases appeared every year. In this way, the researchers maximized comparisons of treatments and subsequent comparisons of grazing treatments for the study, however repeated observations from unique experimental units only occur every third year (Figure 2) (Baumhardt et al., 2009).

Agronomic Information

Winter wheat (cultivar TAM-110, Foundation Seed, College Station, TX) was sown using a high-clearance drill with hoe openers and press wheels during early September to late October when soil water was adequate for wheat establishment. Seasonal weed control in wheat was primarily for flixweed using 2,4-D after grazing as recommended (Owen and Hartzler, 2005). During the 11-month fallow after wheat harvest, weeds were controlled as needed using a Richardson sweep-plow, with fallow after wheat ending in early to mid-June. Grain sorghum, Pioneer hybrid “8699”, was then seeded. Sorghum seed was safened with fluxofenim as required for weed control during the growing season using a commercially available mixture of atrazine and metolachlor. No supplemental nitrogen fertilizer was applied to meet expected dryland yields as the needed nitrogen level was mineralized during the fallow period of this cropping system (Eck and Jones, 1992; Jones, Stewart, and Unger, 1997). No P or K fertilizers were applied because the Pullman clay mineralogy supplies sufficient K to meet crop demand (Johnson et al., 1983) and dryland crop response to applied P fertilizer has shown to be limited (Eck, 1969; 1988). Wheat and sorghum grain yields were taken from hand-harvested samples (Baumhardt et al., 2009).

Grazing

Cattle were stocked in electrically fenced paddocks beginning in January or February, as dryland wheat growth was slow and delayed initial stocking dates. Crossbred steers weighing approximately 254 kilograms were stocked at a target rate of 725 kilograms per hectare depending on available wheat forage. Cattle grazed the entire paddock for approximately one month. Grazing was terminated before hollow stem development in ungrazed wheat. Hollow stem signals the beginning of seed head formation (Redmon et al., 1996). In 2001, grazing was deferred until April due to delayed precipitation and was subsequently grazed out rather than harvested for grain. In 2006, due to significant drought no, grazing occurred as sufficient forage was not available. Cattle gain was calculated as the difference between stocking and pull-off weights, determined after 1-d shrinkage.

Grain and Cattle Prices

To gain an accurate estimate of the profitability of an enterprise, real prices were incorporated into the estimation. Cattle purchase and selling prices were obtained United States Department of Agriculture, Agricultural Marketing Service for Amarillo Livestock Auction, the Cattleman's Livestock Commission Company in Dalhart, Texas, and the Tulia Livestock Auction in Tulia, Texas (USDA - NSS, 2018). The prices from each of these sales corresponding to the sex, weight, and time of the purchase/sale were averaged to estimate the final purchase or sale value. In order to better predict the current market landscape, the prices were taken from the years 2015 to 2017 rather than the (1999-2009) dates of the physical experiment. While the prices during the experiment would reflect current market characteristics, the inclusion of current price and cost information is more reflective of the current production environment. Winter wheat and grain sorghum prices were gathered from the United States Department of Agricultural National Agricultural Statistics Service (USDA – NSS, 2017). Prices were taken from the years 2015 to 2017 and averaged to estimate the final grain price. Monthly average prices per bushel or per hundredweight for winter wheat and grain sorghum, respectively, in Texas was used as the estimated harvest price, and were then transforrmed into price per kilogram. Prices were then coupled with production costs from enterprise budgets for that production year in order to estimate current production prices (2015 to 2017) (Amosson, 2015; 2016; 2017).

Production Costs

Estimating the production costs and returns of agricultural enterprises for planning purposes is a difficult, yet important task of agricultural enterprises. Timing and accurate cost of production are necessary to estimate the potential profitability of alternative enterprise production systems. The Texas Crop and Livestock Enterprise Budgets are projected enterprise budgets prepared by the Texas AgriLife Extension Center to assist farmers and ranchers in estimating “real” economic costs and returns of production, in current dollars (Amosson, 2015; 2016; 2017). Annual budgets were retrieved from years 2015 to 2017 and averaged to estimate variable and fixed costs of production for sorghum, wheat, and cattle production.

Dryland Wheat and Sorghum

Within dryland wheat and sorghum production, several variable costs were incorporated into the analysis. Variable costs incorporated into the estimation were divided into preharvest and harvest expenses. Preharvest costs included: seed at $0.41 per pound, fertilizer at $0.42 per pound, machinery (fuel, labor, and repairs) at $37.75 per hectare, and interest on borrowed capital. Harvest costs included both combine and hauling expenses at $86.00 per hectare. Fixed costs included both machinery and equipment. In 2001, wheat expenses were adjusted as harvest did not occur in the grazing treatments, therefore all harvest expenses were removed as the wheat was 'grazed out'. Furthermore, although no grazing occurred in 2006, due to insufficient wheat production, costs of production remained in the data as producers would have incurred these 'sunk costs.'

Winter Stocker Cattle

Variable costs associated with stocker cattle production were obtained from the winter wheat stocker cattle annual enterprise budgets. Variable costs included hay, cattle processing, labor, veterinarian, salt and mineral, and interest on borrowed capital. These costs were estimated to equal $8.00 per ton for hay, $10.50 for labor, $15.00 for veterinarian costs, $0.43 for mineral and $16.09 per head for interest (Amosson, 2015: 2016; 2017). These costs differ from the expenses incurred in the grain production as they are generated on a per head basis as opposed to a per acre basis with grain enterprises. All costs were incorporated into the estimation and converted to a per hectare basis in order to be coupled with profit estimates from wheat and sorghum grain production. As previously mentioned, purchase costs were assigned to each individual animal as opposed to the estimated purchase expense included in enterprise budgets.

El Nino - La Nina Decision Variable

The El Nino - La Nina Decision Variable predictors were collected from the ENSO Climate Prediction Center of the NOAA (CPC, 2015). El Nino years occurred from 2002 to 2007 of the study, while La Nina years occurred in 2000, 2001, 2008, and 2009 of the study. For the decision process, when an El Nino year was predicted, producers would automatically stock cattle on their wheat fields (Figure 3). During La Nina years, producers would refrain from having cattle graze and would only harvest grain. Once the El Nino - La Nina seasons were established to have occurred, the accuracy of the forecasts was considered. Over the ten-year period, in only one year the prediction did not match the resulting weather pattern. In 2008, an El Nino year was predicted, however according to the equatorial pacific temperatures a La Nina year occurred. The 2008 La Nina year did not have a severe consequence on precipitation in the Texas Panhandle, as the amount of precipitation that year almost matched perfectly the average for the zone. The accuracy of the predictions was deemed a success for the research period, and as the tools that are used continue to increase in accuracy, the predictions that accompany them will become more and more precise.

Profit Functions

In each year, profit was calculated by enterprise (wheat, sorghum, cattle) and by grazing treatment (grazing vs. no grazing).

Sorghum

The equation to calculate profit per hectare for grazed sorghum in year *i* is

$$(1)\ ProfitSG_i = (PS * GS_i) - FCS - VCS$$

where *PS* is the price per kilogram of sorghum grain held constant at $0.24 per kilogram, GS_i is the grain sorghum yield per hectare observed in year *i* for grazed sorghum treatment, *FCS* is fixed costs per hectare held constant at $54.04, and *VCS* is variable costs per hectare held constant at $171.35.

The equation to calculate profit per hectare for ungrazed sorghum in year *i* is

$$(2)\ ProfitSUG_i = (PS * UGS_i) - FCS - VCS$$

where *PS* is the price per kilogram of sorghum grain held constant at $0.24 per kilogram, UGS_i is the grain sorghum yield per hectare observed in year *i* for ungrazed sorghum treatment, *FCS* is fixed costs per hectare held constant at $54.04, and *VCS* is variable costs per hectare held constant at $171.35.

Winter Wheat

The equation to calculate profit per hectare for grazed wheat in year *i* is

$$(3)\ ProfitWG_i = (PW * GW_i) - FCW - VCW$$

where PW is the price per kilogram of winter wheat held constant at $0.15 per kilogram, GW_i is the wheat yield per hectare observed in year *i* for grazed wheat treatment, FCW is fixed costs per hectare held constant at $37.79 with the exception of 2001 when wheat was grazed out due to lack of moisture a late stocking date. For this year harvest expenses were removed changing the fixed cost for grazed wheat in 2001 to $23.63 per hectare. VCW is variable costs per hectare held constant at $91.97.

The equation to calculate profit per hectare for ungrazed wheat in year *i* is

$$(4)\ ProfitWUG_i = (PW * UGW_i) - FCW - VCW$$

where PW is the price per kilogram of winter wheat held constant at \$0.15 per kilogram, UGW_i is the wheat yield per hectare observed in year *i* for ungrazed wheat treatment, $FCW$is fixed costs per hectare held constant at \$37.79, and VCW is variable costs per hectare held constant at \$91.97.

Stocker Cattle

The equation to calculate profit per hectare for owned stocker cattle in year *i* is

$$(5)\ ProfitCattle_i = \frac{\sum_{z=1}^{n}\left((SP_{iz} * SW_{iz}) - (PP_{iz} * PW_{iz}) - VCC\right)}{Hectares}$$

where SP_{iz} is the selling price per kilogram for steer *z* in year *i*, SW_{iz} is the selling weight for steer *z* in year *i*, PP_{iz} is the purchase price per kilogram for steer *z* in year *i*, PW_{iz} is the purchase weight for steer *z* in year *i*, VCC is the variable cost per head held constant at \$39.67 per head. This was summed over all animals and then divided by the total grazing hectares (2.56 hectares) to generate profit per hectare. A three percent death loss was calculated on the average profit from each year in order to present producers with a life-like scenario.

Wheat-Sorghum-Fallow System

After profit was calculated by enterprise, the following system profit functions were estimated; WSF rotation with no grazing, WSF rotation with grazing (producer ownership), and WSF rotation with contract grazing (producer does not own cattle).

The equation to calculate the ungrazed WSF profit system in year *i* is

$$(6)\ WSF\ UG_i = \ ProfitSUG_i + \ ProfitWUG_i$$

where $WSF\ UG_i$ is the profit for WSF rotation without grazing in year *i*. This is the summation of profit for ungrazed sorghum and profit for ungrazed wheat in year *i*.

The equation to calculate WSF grazing ownership profit system in year *i* is

$$(7)\ WSF\ G\ OWN_i = \ ProfitSG_i + \ ProfitWG_i + \ ProfitCattle_i$$

where $WSF\ G\ OWN_i$ is the profit for WSF rotation with grazing in year *i* and is the summation of profit for grazed sorghum, profit for grazed wheat, and profit for operator owned cattle grazed.

The equation to calculate WSF contract grazing profit system in year *i* is

$$(8) WSF\ G\ Contract = ProfitSG_i + \ ProfitWGi + \ \sum_{z=1}^{n}\left((SW_{iz} - PW_{iz}) * (ContractPrice_i)\right)$$

where $WSF\ G\ Contract_i$ is the profit for WSF rotation with contract grazing in year *i*, and is the summation of profit for grazed sorghum, profit for grazed wheat, and total kilograms of gain multiplied the contracted price per kilogram ($1.32) for year *i*.

Sensitivity Analysis

A large determinant of profitability of owner operated cattle grazing is the purchase and sale price of the cattle. In order to further analyze the variability of profit a sensitivity analysis was computed. The best- and worst-case scenarios were estimated. Best case scenario is represented by using the lowest average purchase price coupled with the highest sales price. Worst case scenario incorporated the highest average purchase price coupled with the lowest sales price. The prices associated with the highest purchase and lowest sale prices were $6.62 per kilogram and $3.27 per kilogram respectively for this buy high sell low, or worst-case scenario. Cattle prices corresponding to the lowest total purchase price and the highest total sale price were then incorporated into the profit function for stocker cattle to estimate the best-case scenario. The prices associated with the lowest purchase and highest sale prices were \$3.49 per kilogram and \$6.36 per kilogram respectively for this buy low sell high, or best-case scenario.

Data

Sorghum yields and profits were analyzed comparing grazed versus ungrazed plots using tests for normality, proc ttest, and the proc glm power in SAS (SAS, 2009). They were found to be normal, but the ttest established no difference ($p > 0.05$) for both yields and profits. The power needed to find this difference was estimated at 820 and 9,060 respectively. Wheat yields and profits were also analyzed by comparing grazed versus ungrazed plots using test for normality, proc ttest, and the proc glm power in SAS (SAS, 2009). Both were found to be non-normal and were transformed using the square root function. Once transformed both yields and profits were found to be non-different with both ($p > 0.05$). The power estimated to find a statistical difference was 620 and 380 respectively. Cattle profits comparing owned versus contracted options were analyzed for normality and using the proc ttest as well as the proc glm power tests in SAS (SAS, 2009). Cattle profits were found to be non-normal and were transformed using the square root function. Once normal, no difference ($p > 0.05$) was discovered. The proc glm power test presented an n of 440 needed to find a statistical difference. Finally, the overall system profits of ungrazed, grazed with ownership, grazed with contract, decision variable grazed with ownership, and the decision variable grazed with contract were all tested for normality and for a statistical difference. They were found to be normal, but not different ($p > 0.05$). The lack of power in all statistical analyses was the contributing factor in discovering no significant differences.

CHAPTER 4 - RESULTS

Sorghum

Using the WSF rotation without grazing yielded an average sorghum profit per hectare of $374.72 (Table 1). Revenue was estimated at $600.11 with a $0.24 price per kilogram and an average yield of 2,350 kilogram per hectare (Table 2). Variable costs were estimated at $171.35 per hectare, where custom harvest was 17%, herbicide and crop insurance 14%, and consisted of 17% custom harvest expenses, 14% herbicide and crop insurance, 14% fertilizer and application, and 14% tractor labor. Fixed costs were estimated at $54.04 per hectare and were largely comprised of machinery depreciation, investments in equipment, and rent. This brought the total cost of production per hectare for sorghum to $225.39 (Table 1). Sorghum grazed yield was lowest in 2003 at 0.00 kilograms per hectare and highest in 2005 at 3,910 kilograms per hectare. The ungrazed sorghum yield was lowest in 2003 at 0.00 kilograms per hectare and highest in 2005 at 3,895 kilograms per hectare (Table 2).

Wheat

The WSF rotation with ungrazed wheat yielded an average profit per hectare of $34.62 (Table 3). Revenue was estimated at $199.34 per hectare with a $0.15 price per kilogram and an average yield of 1,198 kilograms per hectare (Table 2). Variable costs were estimated at $126.93, where both seed and custom harvest were 18% and crop insurance was 13%. Fixed costs were estimated at $37.79 per hectare and consisted largely of rent and implement depreciation. This brought the total cost of production per hectare for ungrazed wheat to $164.72 (Table 3). Ungrazed wheat yield was highest in 2007 at 3,079 kilograms per hectare and lowest in 2001 and 2006 at 0.00 kilograms per hectare. The grazed wheat had its highest yield in 2007 at 2,781 pounds per hectare and the lowest in 2001 and 2006 at 0.00 kilograms per hectare (Table 4). The grazed wheat had an average yield of 1,140 kilograms per hectare, which was 58 kilograms less than the average for the ungrazed wheat. Variable costs, fixed costs and price per kilogram were kept constant. The average profit for the grazed wheat was estimated $29.69 per hectare (Table 5).

Winter Stockers

Calves introduced into the WSF rotation could graze growing wheat and the sorghum stover in conjunction. The total gain, on average, for these calves was 23 kilograms over the 30-day average grazing period (Table 6). The ADG was 0.68 kilograms. Variable costs to produce these calves was estimated at $97.94 per hectare. The profit per hectare when owning the calves was estimated at $16.83 per hectare. The profit when contracting wheat out to another producer was $13.30 per hectare (Table 6). The highest profit on owned stockers occurred in 2008 and was $67.41 per hectare (Table 7). The highest profit on contracted stockers was also in 2008 and was $29.33 per hectare. The lowest profit per hectare for the stockers was in 2005 with the profit for owned cattle at ($10.86) per hectare while contracted cattle was estimated at $5.42 per hectare. The contracted cattle never lost money during the experimental period, while owned cattle lost money in two years, or 22 percent of the time (Table 7).

In order to further investigate the possible fluctuation of income or lack thereof associated with the cattle enterprise, a sensitivity analysis was conducted. In this analysis, two sides of the profit spectrum were evaluated. Initially, the extreme low when a producer would have bought cattle at the highest price of the study and sold at the lowest. Secondly is the extreme high, when a producer would have purchased cattle at the lowest price and sold at the highest. This sensitivity analysis further indicated how contracting cattle may be the best option, as these price fluctuations have no effect on contract profit. If the producers bought cattle at the high prices and sold at the low prices, they would lose money 100 percent of the time, with the greatest loss occurring in 2003 at ($123.10) per hectare. The lowest loss for this scenario occurred in 2009 at ($86.33) per hectare. The other side of the spectrum had severely increased profits, with a high at $140.22 per hectare in 2008 and the lowest profit happening in 2002 at $85.99 per hectare (Table 7). These excessive differences in profit demonstrate how variable profit from cattle ownership could be if severe price fluctuations occurred and cattle marketing or risk management practices were not incorporated into the system.

System Profit

Average profit for the ungrazed system was the lowest for the ten-year period at $409.08 per hectare (Table 8). The highest profit occurred in 2007 at $1,133.89 per hectare. The lowest system profit was in 2003 at ($314.25) per hectare. This occurred largely because there was no grain harvested from sorghum during this year, leading to an overall loss. The highest average profit was observed in the grazed system with cattle ownership at $471.57 per hectare. In 2007, the highest profit for the grazed system was observed at $1,282.94, while the lowest was in 2003 at ($272.99) per hectare. Again, this was largely due to the loss on sorghum. Contract grazing yielded a similar outcome with average profit of $467.60 per hectare. The highest contract system profit was in 2007 with at $1,297.06 per hectare and the lowest was in 2003 at $270.80 per hectare (Table 8).

El Nino - La Nina Decision

Incorporation of an El Nino - La Nina decision variable would be vital in producers making grazing decisions. Across the ten-year study period, four years were La Nina, the first two (2000 and 2001) along with the final two years (2008 and 2009). The years from 2002-2007 were El Nino (Figure 3). Average crop profit in La Nina years for sorghum was $392.71 per hectare and ($61.72) per hectare for wheat (Table 9). In El Nino years, sorghum profit was $362.73 per hectare and the wheat profit for those years was $98.42 per hectare (Table 10). It was assumed producers would not graze during La Nina years, therefore the system profit in those years does not include grazing. Average profit from grazing during the El Nino years was $3.00 per hectare for owned calves and $7.90 per hectare for contracted calves (Table 11). The average annual profit per hectare by system was highest for the decision variable with contract grazing at $492.69 per hectare with a standard deviation (SD) of $454.54. The second highest per hectare profit system was also achieved using the decision variable and had a SD of $449.94 with a profit per hectare of $489.74. The lowest was the ungrazed system with an estimated profit of $409.08 per hectare with a SD of $446.62 per hectare. (Table 12 and Figure 4).

CHAPTER 5 - CONCLUSION AND SUMMARY

Through this study, economic evaluation of incorporating grazing into the WSF rotational system is estimated. Additionally, cattle ownership versus contract grazing is analyzed to determine profit generated as well as variation. Lastly, the study evaluated the incorporation of an El Nino - La Nina grazing decision variable to assist producers in when it is best to focus on supplemental income with grazing versus grain only production system.

Grazing cattle on a wheat-sorghum-fallow rotation would provide producers with another source of revenue for the dryland production system. Also incorporated is the decision of cattle ownership versus contract grazing the wheat to another producer. Owning the cattle when not using the decision variable netted producers the highest profit, on the other hand, contracting the cattle when using the decision variable netted the highest profit. Lastly, incorporating the El Nino - La Nina decision variable can assist producers in the grazing decision as these systems are dependent on precipitation rather than irrigation. The publication in late summer predicting the ENSO cycle can aid producers in their production decisions. For instance, when ENSO predictions are released in mid to late August, producers can then use the decision variable to make their grazing decisions even before they have planted wheat.

The incorporation of cattle grazing into the WSF rotation helped producers increase profit. With the traditional ungrazed rotation, profits per hectare were the lowest of any combination evaluated. The introduction of cattle into the system increased profits from 14% at a minimum, and 20% at a maximum, overall profits from wheat grain were decreased by grazing cattle. Profits fell from $34.36 per hectare to $29.69 per hectare, a 14% decrease (Table 3 and 5). Although a decrease is observed, the overall system profit increases due to weight gained from cattle production. Owning the cattle added $15.81 per hectare and contracting the cattle added $11.97 per hectare to the profit of the system. Yield for wheat which was not grazed was higher than the grazed yield, as expected. It has been shown that grazing cattle does negatively impact grain yields on wheat, but also shown that cattle have no direct impact on the grain yield of sorghum. It was found in the study that yield on the plots which had previously been grazed were much larger than the ones that had not. Though there is no correlation between the yield of sorghum and the grazing of cattle, because sorghum grain is harvested before cattle grazing is introduced into the system. Further research to discover if there is a correlation between grazing the sorghum stover and subsequent yields is warranted.

Although not significant, there was a small numerical difference in profit between owning and contracting cattle estimated at $3.94 per hectare. While the difference in profit was not significant ($p > 0.05$), it is important to note that ownership of cattle requires additional capital investment as well as adding additional risk to the operation. Each individual producer has a different utility function and preference for risk. Here, the idea of risk is primarily defined as a loss of money on cattle when owned versus contracted. When cattle are incorporated into the WSF system, additional risk is taken on along with additional capital requirements. Marketing risk on the purchase and sale prices received can have a dramatic impact on the profitability of the enterprise. To evaluate this the sensitivity analysis was estimated. The severe high and severe low sensitivity analysis further highlights the associated risk of losing money on introducing cattle grazing. Furthermore, additional production risk with livestock enterprises should be evaluated by the producer. Morbidity and mortality can have a dramatic impact on cattle profits. The additional labor and knowledge required for a livestock enterprise should be clearly evaluated when a producer is deciding if cattle production should be incorporated into the operation. To further highlight the risk associated with cattle ownership, during the ten years examined, two years yielded a loss rather than a profit when owning cattle, while contracting yields a steady positive cash inflow. Of the nine years cattle were grazed (2006 no grazing occurred), producers who owned their own cattle lost money 22% of the time. However, with the severe low outcome when producers may possibly buy high and sell low, owning cattle lost money ten consecutive years. At the same time, if a producer bought low and sold high, profit would be extremely high for all years. For a producer who has capital restrictions, the possibility of sustaining a loss may deter cattle ownership. A producer who is opposed to suffering a loss could contract his wheat out to negate the risk associated with cattle ownership, and to garner a steady profit. If sufficient capital is available, cattle ownership could potentially be more feasible to the operation. For example, a producer with 2,500 hectares could increase profit by almost 10,000 dollars with cattle ownership.

In addition to the decision on whether to own or contract cattle, the decision variable of when to graze cattle was also explored. The El Nino - La Nina decision variable was integrated into the study as an aid to the grazing decision made by producers. An El Nino year would have indicated grazing, while the decision of whether to own or lease out the grazing would still be their decision. The La Nina prediction would tell producers grazing is not encouraged. In the study, the overall average profit for both owning and contracting cattle was increased above all other systems when the decision variable was used. In La Nina years, average profit was increased by foregoing grazing, as opposed to grazing cattle. The La Nina years of non-grazing averaged profits of $330.99 per hectare, whereas average profits for those same years for owning and contract grazing were $285.57 per hectare and $268.61 per hectare respectively (Table 13). For the years when the decision variable was used, and El Nino years were presented, the additional profit of adding cattle as opposed to simply harvesting grain was almost $100 per hectare. It rose from an average of $461.14 per hectare to $595.58 per hectare for owned grazing and increased to $600.48 per hectare for contract grazing (Table 14). When producers incorporate grazing, profits increased. Additionally, when producers used the El Nino - La Nina decision variable on deciding when to graze, profits once again increased when compared to the ungrazed and to the owned grazed and contract grazed systems.

The largest limitation of this study is the sample size. Statistically significant differences were not observed largely due to the lack of power and small sample analyzed. If possible, further trials and replication could be incorporated to obtain better data for statistical analysis. The results here are largely targeted for producers. It is anticipated that with experimental replication, results would further confirm the differences observed between grazing and non-grazing, contracting and owning, and incorporation of a grazing decision variable.

REFERENCES

Almas, L., W. Colette, and R. Taylor. 2007. Implications of groundwater conservation policies: An economic analysis. *In* Proceedings of the 2007 World Environmental and Water Resources Congress. Tampa, FL. USA: 1-10.

Amosson, S. at Texas A&M Extension. 2015. Rotation, sorghum-fallow-wheat, minimum till, wheat with grazing. https://agecoext.tamu.edu/wp-content/uploads/2015/01/2015D1WheatRotation.pdf (accessed 1 January 2017).

Amosson, S. at Texas A&M Agrilife Extension. 2016. Rotation, sorghum-fallow-wheat, minimum till, wheat with grazing. https://agecoext.tamu.edu/wp-content/uploads/2015/12/2016D1WheatRotation.pdf. (accessed 1 January 2017).

Amosson, S. at Texas A&M Agrilife Extension. 2017. Rotation, sorghum-fallow-wheat, minimum till, wheat with grazing. https://agecoext.tamu.edu/wp-content/uploads/2016/12/2017D1WheatRotation.pdf. (accessed 1 January 2017).

Anderson, J.D., C. Lacy, C.S. Forest, and R.D. Little. 2004. Expected utility of stocker cattle ownership vs contract grazing in the Southeast. Journal of Agricltural and Applied Economcs 36.3: 719-730.

Baumhardt, R.L., and R.L. Anderson. 2006. Crop choices and rotation principles. p. 113-139. *In* G.A. Peterson et al. (ed.) Dryland agriculture. 2nd ed. Agron. Monogr. 23. ASA, CSSA, and SSSA, Madison, WI.

Baumhardt, R.L., A.S. Bruinsma, A.V. Goodchild, P. Gregorini, B. Hartwell, H.V. Keulen, M.A. Slingerland, and A.M. Whitbread. 2006. Mixed crop livestock systems in semiarid regions. *In* Dryland Agriculture, Agonomy Monograph. American Society of Agronomy.

Baumhardt, R.L., and J. Salinas- Garcia. 2006. Dryland agriculture in Mexico and the U.S. Southern Great Plains. p. 341-364. *In* G.A. Peterson et al. (ed.) Dryland agriculture. 2nd ed. Agron. Monogr. 23. ASA, CSSA, and SSSA, Madison, WI.

Baumhardt, R.L., R.C. Schwart, L.W. Greene, and J.C. Macdonald. 2009. Cattle gain and crop yield for a dryland wheat-sorghum-fallow roation. Agronomy Journal 101.1: 150-158.

Bechtel, W. 2019. Get the facts and projections on 2019 from Cattle Fax. https://www.drovers.com/article/get-facts-and-projections-2019-cattlefax. (accessed 17 March 2019).

Clarke, R.T.J., and C.S.W. Reid. 1974. Foamy bloat of cattle. A review. Journal of Dairy Science 57.7: 753-785.

Colaizzi, P.D., P.H. Gowda, T.H. Marek, and D.O. Porter. 2009. Irrigation in the Texas High Plains: A brief history and potential reductions in demand. Irrigation and Drainage 58.3: 257-274.

CPC. 2015. Historical El Nino/La Nina episodes (1950-present) Cold and warm episodes by season. Climate Prediction Ctr. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ ensostuff/ensoyears.shtml (accessed 8 January 2017).

Dao, T.H. 1993. Tillage and winter wheat residue management effects on water infiltratoin and storage. American Society of Agronomy. p. 1586-1595.

Decker, J.E., F.M. Epplin, D.L. Morley, and T.F. Peeper. 2009. Economics of five wheat production systems with no-till and conventional tillage. Agronomy Journal 101.2: 364-372.

Dhuyvetter, K.C., J.R. Shroyer, G.L. Kuhl, D.L. Fjell, L.N. Langemeier, and J.O. Fritz. 1993. Wheat pasture in Kansas. *In* Kansas State University Cooperate Extension Service. Manhattan, Kansas: C-713.

Dhuyvetter, K.C., C.R. Thompson, C.A. Norwood, and A.D. Halvorson. 1996. Economics of dryland cropping systems in the great plains: A review. Journal of Production Economics 9: 216-222.

Eck, H.V. 1969. Restoring productivity on Pullman silty clay loam subsoil under limited moisture. Journal of Agronomy. 33:578–581.

Eck, H.V. 1988. Winter wheat response to nitrogen and irrigation. Journal of Agronomy. 80:902–908.

Eck, H.V., and O.R. Jones. 1992. Soil nitrogen status as aff ected by tillage, crops, and crop sequences. Journal of Agronomy. 84: 660–668.

Epplin, F.M., I. Hossain, and E.G. Krenzer Jr. 2000. Winter wheat fall-winter forage yield and grain yield response to planting date in a dual purpose system. Agricultural Systems 63: 161-173.

Gershunov, A., and T.P. Barnett. 1998. ENSO influence on intraseasonal extreme rainfall and temperature frequencies in the Contiguous United States observations and model results. Journal of Climate 11.7: 575-586.

Harrison, R.W., B.W. Bobst, F.J. Benson and L. Meyer. 1996. Analysis of the risk of management properties of grazing contracts versus futures and options contracts. Southern Agricultural Economics Association: 247-262.

Horn, G.W., P.A. Beck, J.G. Andrae, and S.I. Paisley. 2005. Designing supplements for stocker cattle grazing wheat pasture[1,2]. Journal of Animal Science 83 (E. Suppl.): E69-E78.

Johnson, W.C., E.L. Skidmore, B.B. Tucker, and P.W. Unger. 1983. Soil conservation Central Great Plains winter wheat and range region. Dryland Agriculture Agronomy Monograph: 197-217.

Jones, O.R., and T.W. Popham. 1997. Cropping and tillage systems for dryland grain production in the Southern High Plains. Agronomy Journal 89: 222-232.

Jones, O.R., B.A. Stewart and P.W. Unger. 1997. Management of dry farmed southern great plains soils for sustained productivity. In E.A. Paul et al. Soil organic matter in temperate agroecosystems: long term experiments in North America: 987-401.

Lucas, F.D. 2013. H.R. 2642 – Agricultural Act of 2014. https://www.congress.gov/bill/113th-congress/house-bill/2642. (accessed 8 May 2019).

Mann Library, A.R. 2017. Winter Wheat and Canola Seedings 2015-2017. National Agricultural Statistics Service, Southern Plains, U.S.

Mauget, S.A., and D.R. Upchurch. 1999. El Nino and La Nina related climate and agricultural impacts over the Great Plains and Midwest. Journal of Production Agriculture: 203-215.

Mauget, S.A., J. Zhang, and K. Jonghan. 2009. The value of ENSO forecast information to dual-purpose winter wheat production in the U.S. Southern High Plains. Journal of Applied Meteorology and Climatology 48.10: 2100-117.

McDuffey, R.K., L.F Richardson, and J.I.D. Wilkinson. 2001. Ionophores for dairy cattle. Current status and future outlook. Journal of Dairy Science: 194-203.

McGuire, V.L. 2017. Change in water storage in the High Plains aquifer predevelopment (about 1950) to 2015. Geological Society of America, Northeast Section 52nd Annual Meeting 2017.

Min, B.R., W.E. Pinchak, J.D. Fulford, and R. Puchala. 2005. Wheat pasture boat dynamics, in vitro ruminal gas production and potential bloast mitigation with condensed tannins. Journal of Animal Science 83: 1322-1331.

Owen, R.G., and M.D.K. Hartzler. 2005. Herbicide manual for agricultural professionals. *In* Extension publication. Iowa State University cooperative extension service: WC-92.

Peterson, G.A., A.D. Halvorson, J.L. Havlin, O.R. Jones, D.J. Lyon and D.L. Tanaka. 1998. Reduced tillage and increasing cropping intensity in the great plains conserves soil C. Soil and Tillage Research 47: 207-218.

Raney, W.A., and A.W. Zingg. 1957. Principles of tillage. Yearbook of Agriculture: 277-281.

Redmon, L.A., E.G. Krenzer Jr, D.J. Bernardo, and G.W. Horn. 1996. Effect of wheat morphological stage at grazing termination on economic return. Agronomy Journal 88: 94-97.

SAS Institute. 2009. SAS OnlineDoc 9.1.3 SAS Inst., Cary, NC.

Teegerstrom, T., G. D'Souza, P. Osborne, and K. Jones. 1997. To contract or not to contract? A decision theory and portfolio analysis of cattle contract grazing. Northeastern Agricultural and Resource Economics Association: 205-215.

USDA-NSS. 2017. Livestock prices for Amarillo Livestock Auction, Dalhart Cattle Commission and Tulia Livestock Auction. Email correspondence. 2018.

Walker, J. 2018. First look at 2018 acreage estimates. http://texasfarmbureau.org/first-look-2018-acreage-estimates-crop-outlook/. (accessed 6 August 2019).

Williams, J., R. Llewelyn, D. Pendell, A. Schlegel and T. Dumler. 2010. A risk analysis of converting conservation reserve program acres to a wheat sorghum fallow roation. Agronomy Journal 102: 612-662

APPENDIX A FIGURES AND TABLES

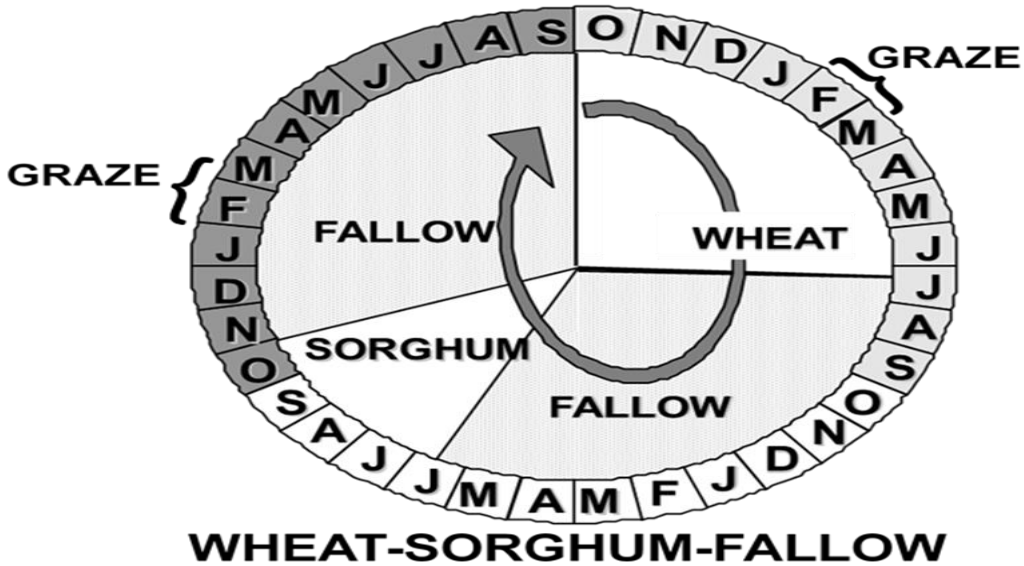

Figure 1. Wheat sorghum fallow rotational grazing system

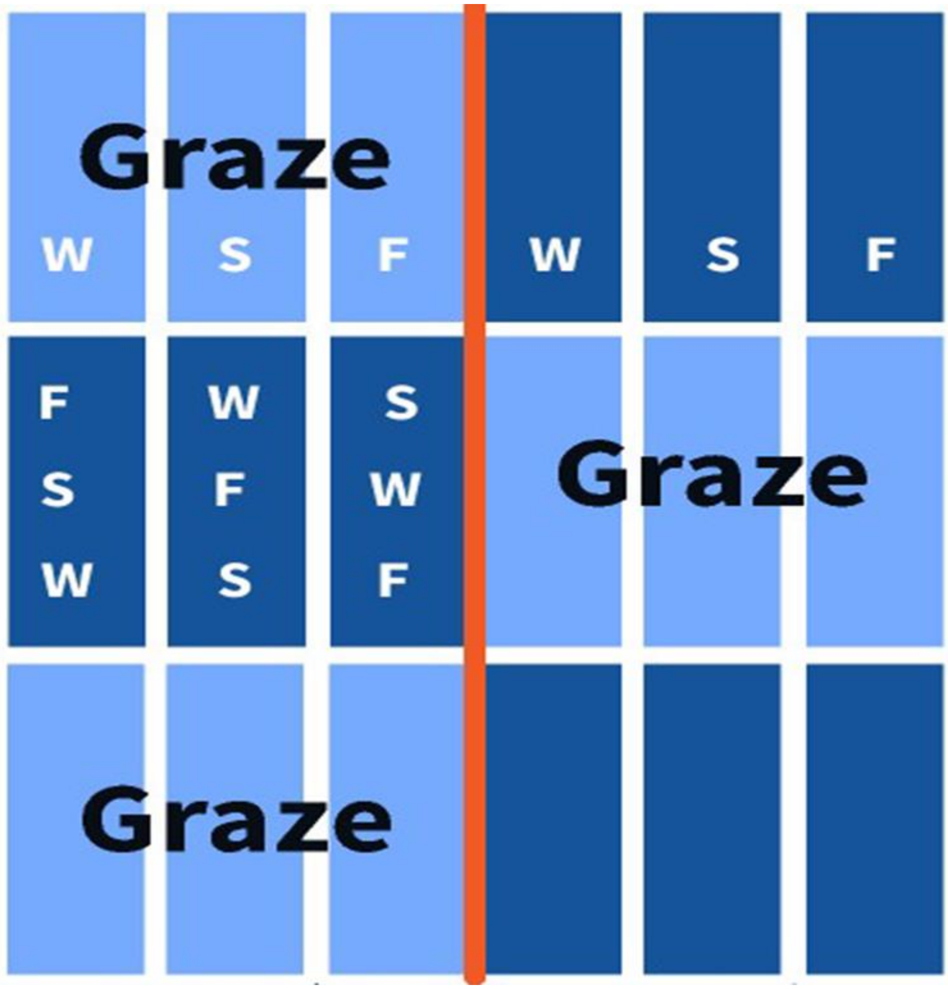

Figure 2. Graphical representation of experimentally designed plots established at Bushland Research Laboratory

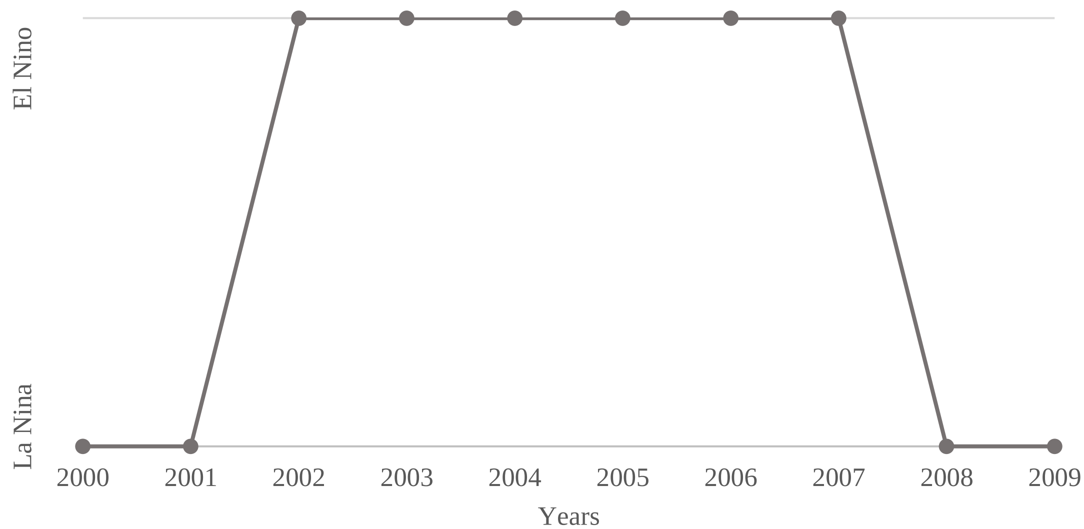

Figure 3. Years that El Nino, La Nina occurred 2000-2009

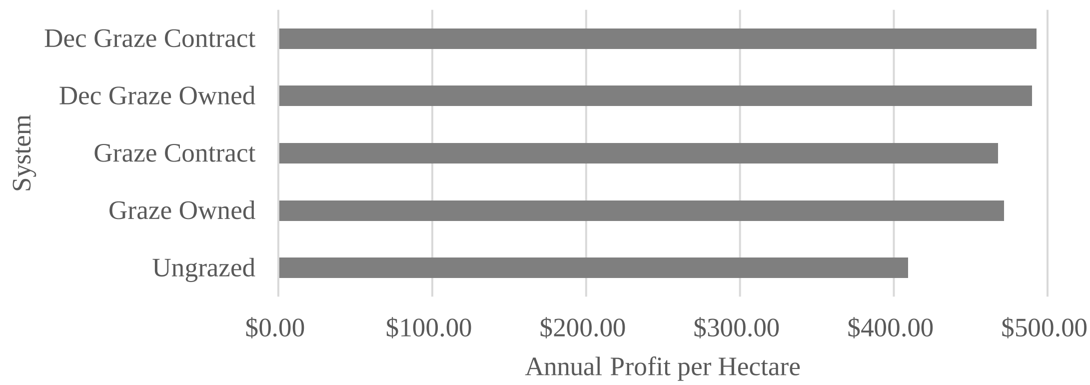

Figure 4. Average system profits, 2000-2009

Table 1. Average Revenue, Total Costs, and Average Profit per Hectare for Ungrazed Sorghum, 2000-2009

Revenue	Variable Cost	Fixed Cost	Total Cost	Profit
$600.11	$171.35	$54.04	$225.39	$374.72

Table 2. Sorghum Yield for Grazed and Ungrazed Plots

Year	Grazed Yield (kg/ha)	Ungrazed Yield (kg/ha)
2000	2,775	2,856
2001	2,294	2,632
2002	2,021	688
2003	0.00	0.00
2004	2,033	1,766
2005	3,910	3,895
2006	3,246	3,400
2007	3,873	3,722
2008	1,834	1,782
2009	1,517	1,995
Average	2,350	2,274

Table 3. Average Revenue, Total Costs, and Average Profit per Hectare for Ungrazed Wheat, 2000-2009

Revenue	Variable Cost	Fixed Cost	Total Cost	Profit
$199.34	$126.93	$37.79	$164.72	$34.62

Table 4. Wheat Yield for Grazed and Ungrazed Plots

Year	Grazed Yield (kgs/ha)	Ungrazed Yield (kgs/ha)
2000	750	892
2001	0.00	0.00
2002	1,895	1,461
2003	856	719
2004	2,165	1,728
2005	1,632	2,395
2006	0.00	0.00
2007	2,781	3,079
2008	692	885
2009	632	822
Average	1,140	1,198

Table 5. Average Revenue, Total Costs, and Average Profit per Hectare for Grazed Wheat, 2000-2009

Revenue	Variable Cost	Fixed Cost	Total Cost	Profit
$194.41	$126.93	$37.79	$164.72	$29.69

Table 6. Average Gain, Average Daily Gain (ADG), Variable Costs, and Average Profit per Hectare for Winter Stocker Calves both Owned and Contracted, 2000-2009

Average Gain (kgs)	ADG (kgs)	Variable Cost	Owned Profit	Contract Profit
23	0.68	$97.94	$16.83	$13.30

Table 7. Average Profit per Year per Hectare, for Owned and Contracted Stocker Calves, 2000-2009

Year	Hi/Lo Sensitivity*	Lo/High Sensitivity*	Owned Profit	Contracted Profit
2000	($89.98)	$104.34	$34.01	$18.46
2001	($105.52)	$102.94	$2.61	$9.27
2002	($89.97)	$85.99	$7.62	$9.18
2003	($123.10)	$117.48	$9.80	$11.99
2004	($119.66)	$127.34	$19.82	$15.10
2005	($115.69)	$103.24	($10.86)	$5.42
2007	($103.20)	$89.69	($8.30)	$5.75
2008	($104.54)	$140.22	$67.41	$29.33
2009	($86.33)	$96.97	$32.46	$15.22
Average	($104.22)	$107.58	$17.17	$13.30

Note: 2006 was omitted because no cattle were grazed.
*Sensitivity analysis was completed taking the highest purchase price coupled with the lowest sale price and the lowest purchase price coupled with the highest sale price.

Table 8. Profit per Hectare by System, 2000-2009

Year	Ungrazed	Hi/Lo Sensitivity*	Owned Grazed	Lo/Hi Sensitivity*	Contract Grazed
2000	$615.82	$303.78	$427.77	$498.10	$412.22
2001	$313.66	$165.58	$272.31	$372.64	$275.34
2002	$18.66	$250.70	$348.29	$426.66	$349.85
2003	($314.25)	$386.29	($272.99)	($145.71)	($270.80)
2004	$355.46	$465.86	$605.34	$712.86	$600.26
2005	$1,072.94	$983.18	$1,088.01	$1,202.11	$1,104.29
2006	$500.16	$521.86	$521.86	$521.86	$521.86
2007	$1,133.89	$1,188.04	$1,282.94	$1,380.93	$1,297.06
2008	$177.48	$152.43	$324.38	$397.19	$286.30
2009	$217.01	($0.99)	$117.80	$182.31	$100.56
Average	$409.08	$441.67	$471.57	$554.90	$467.69

*Sensitivity analysis was completed taking the highest purchase price coupled with the lowest sale price and the lowest purchase price coupled with the highest sale price.

Table 9. Sorghum and Wheat Profit in La Nina Years

Year	Sorghum	Wheat
2000	$643.69	($27.87)
2001	$458.67	($145.01)
2008	$204.6	($27.12)
2009	$263.89	($46.88)
Average	$392.71	($61.72)

Table 10. Sorghum and Wheat Profit in El Nino Years

Year	Sorghum	Wheat
2002	($92.26)	$110.92
2003	($251.90)	($62.35)
2004	$233.15	$122.31
2005	$846.46	$226.48
2006	$684.25	($184.09)
2007	$756.66	$377.23
Average	$362.73	$98.42

Table 11. Owned and Contracted Stocker Cattle Profit in El Nino Years

Year	Owned	Contracted
2002	$7.62	$9.18
2003	$9.80	$11.99
2004	$19.82	$15.10
2005	($10.86)	$5.42
2007	($8.37)	$5.75
Average	$3.60	$9.79

Note: 2006 would have been an El Nino year but during the experiment the decision to not graze was made due to drought like precipitation.

Table 12. Average System Profits per Hectare, 2000-2009

Dec* Con** Graze	Dec* Own*** Graze	Con** Graze	Own*** Graze	Ungrazed
$492.69	$489.74	$467.63	$471.57	$409.08

Where: Dec* = decision, Con** = contract grazing, Own*** = cattle ownership

Table 13. Profits of La Nina Decision Years Compared to Owning and Contracting Grazing Years

Year	La Nina Profit	Owned Grazing	Contract Grazing
2000	$615.82	$427.77	$412.22
2001	$313.66	$272.31	$275.34
2008	$177.48	$324.38	$286.30
2009	$217.01	$117.80	$100.56
Average	$330.99	$285.57	$268.61

Table 14. Profits of El Nino Decision Years Compared to Non-Grazing Harvest Years

Year	El Nino Owned	El Nino Contract	Non-Grazing
2002	$348.29	$349.85	$18.66
2003	($272.99)	($270.80)	($314.25)
2004	$605.34	$60.62	$355.46
2005	$1,088.01	$1,104.29	$1,072.94
2006	$521.86	$521.86	$500.16
2007	$1,282.94	$1,297.06	$1,133.89
Average	$595.58	$510.48	$461.14

Table 15. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2000

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	222	$1,015.56	256	$1154.13	0.97	$34.2	$134.41	$39.67	$36.41
2	227	$1,047.48	258	$1156.76	0.89	$31.6	$106.19	$39.67	$8.25
3	227	$1,041.00	258	$1154.64	0.92	$32.3	$110.23	$39.67	$12.29

Table 16. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2001

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	254	$1,162.86	267	$1,202.14	0.44	13.7	$38.09	$39.67	($1.58)
2	248	$1,143.88	265	$1,185.86	0.59	17.4	$40.72	$39.67	$1.05
3	250	$1,153.47	274	$1,224.95	0.81	24.8	$69.31	$39.67	$29.64

Table 17. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2002

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	212	$965.77	230	$1,032.59	0.63	18.1	$64.82	$39.67	$25.15
2	216	$994.97	230	$1,027.48	0.48	14.1	$31.53	$39.67	($8.14)
3	208	$960.44	225	$1,005.55	0.57	16.3	$43.75	$39.67	$4.08

Table 18. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2003

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	293	$1,344.58	318	$1,434.49	0.72	25.4	$89.91	$39.67	$50.24
2	291	$1,340.92	312	$1,396.71	0.61	21.3	$54.06	$39.67	$14.39
3	288	$1,329.24	302	$1,350.34	0.39	13.6	$20.25	$39.67	($19.42)

Table 19. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2004

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	293	$1,339.21	320	$1,440.11	0.69	27.2	$97.87	$39.67	$58.20
2	294	$1,356.27	324	$1,451.87	0.78	30.4	$92.74	$39.67	$53.07
3	293	$1,350.95	301	$1,443.75	0.55	21.3	$53.01	$39.67	$13.34

Table 20. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2005

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	267	$1,219.92	270	$1,217.46	0.12	3.6	($2.80)	$39.67	($42.47)
2	267	$1,231.07	279	$1,251.52	0.42	12.7	$19.72	$39.67	($19.95)
3	265	$1,222.00	282	$1,263.53	0.58	17.2	$40.13	$39.67	$0.46

Table 21. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2007

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	235	$1,076.76	244	$1,096.94	0.28	8.2	$19.34	$39.67	($20.33)
2	235	$1,083.20	251	$1,123.59	0.56	16.3	$39.18	$39.67	($0.49)
3	236	$1,088.08	241	$1,080.27	0.19	5.4	($7.91)	$39.67	($47.58)

Table 22. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2008

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	279	$1,273.86	331	$1,490.67	1.46	52.6	$210.30	$39.67	$170.63
2	279	$1,289.31	332	$1,485.04	1.45	52.6	$189.86	$39.67	$150.19
3	279	$1,283.99	330	$1,476.49	1.43	51.7	$186.73	$39.67	$147.06

Table 23. Cattle Data Including Pasture, Purchase and Sell Weights (kg), Purchase and Sale Prices, Gain (kg), Revenue, Costs, and Average Profits per Hectare by Pasture, 2009

Pasture	Purchase Weight	Purchase Price	Sell Weight	Sell Price	Daily Gain	Total Gain	Revenue	Variable Cost	Profit
1	214	$979.77	241	$1,085.70	0.93	26.8	$102.75	$39.67	$63.08
2	215	$990.78	241	$1,077.57	0.89	25.9	$84.18	$39.67	$44.51
3	215	$992.09	244	$1,093.22	1.01	29.1	$97.90	$39.67	$58.23

Table 24. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2000

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	750	$126.93	$37.39	$0.15	($44.12)
UG Wheat	892	$126.93	$37.39	$0.15	($21.36)
Grazed Sorghum	2,856	$171.35	$54.04	$0.24	$468.37
UG Sorghum	2,775	$171.35	$54.04	$0.24	$448.71

Table 25. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2001

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat*	0.00	$91.97	$37.39	$0.15	($129.75)
UG Wheat*	0.00	$91.97	$37.39	$0.15	($52.55)
Grazed Sorghum	2,294	$171.35	$54.04	$0.24	$331.94
UG Sorghum	2,632	$171.35	$54.04	$0.24	$414.03

*Wheat in 2001 was grazed out so there are no harvest costs associated with the variable costs.

Table 26. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2002

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	1,895	$126.93	$37.39	$0.15	$139.77
UG Wheat	1,461	$126.93	$37.39	$0.15	$69.99
Grazed Sorghum	2,021	$171.35	$54.04	$0.24	$265.62
UG Sorghum	688	$171.35	$54.04	$0.24	($58.22)

Table 27. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2003

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	856	$126.93	$37.39	$0.15	($27.22)
UG Wheat	719	$126.93	$37.39	$0.15	($49.17)
Grazed Sorghum	0.00	$171.35	$54.04	$0.24	($225.39)
UG Sorghum	0.00	$171.35	$54.04	$0.24	($225.39)

Table 28. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2004

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	2,165	$126.93	$37.39	$0.15	$183.12
UG Wheat	1,728	$126.93	$37.39	$0.15	$112.93
Grazed Sorghum	2,018	$171.35	$54.04	$0.24	$264.71
UG Sorghum	1,766	$171.35	$54.04	$0.24	$203.54

Table 29. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2005

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	1,632	$126.93	$37.39	$0.15	$97.58
UG Wheat	2,395	$126.93	$37.39	$0.15	$220.16
Grazed Sorghum	3,910	$171.35	$54.04	$0.24	$724.26
UG Sorghum	3,895	$171.35	$54.04	$0.24	$720.65

Table 30. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2006

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	0.00	$126.93	$37.39	$0.15	($164.72)
UG Wheat	0.00	$126.93	$37.39	$0.15	($164.72)
Grazed Sorghum	3,246	$171.35	$54.04	$0.24	$563.08
UG Sorghum	3,400	$171.35	$54.04	$0.24	$600.58

Table 31. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2007

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	2,781	$126.93	$37.39	$0.15	$282.16
UG Wheat	3,079	$126.93	$37.39	$0.15	$330.10
Grazed Sorghum	3,873	$171.35	$54.04	$0.24	$715.39
UG Sorghum	3,722	$171.35	$54.04	$0.24	$678.71

Table 32. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2008

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	692	$126.93	$37.39	$0.15	($21.65)
UG Wheat	885	$126.93	$37.39	$0.15	($9.11)
Grazed Sorghum	1,834	$171.35	$54.04	$0.24	$89.10
UG Sorghum	1,782	$171.35	$54.04	$0.24	$83.99

Table 33. Crop Data Including Yield (kg/ha), Variable Cost, Fixed Cost, Price ($/kg), and Profit per Hectare, 2009

Type	Kg/Ha	Variable Cost	Fixed Cost	Price/kg	Profit/Ha
Grazed Wheat	632	$126.93	$37.39	$0.15	($63.18)
UG Wheat	822	$126.93	$37.39	$0.15	($32.69)
Grazed Sorghum	1,517	$171.35	$54.04	$0.24	$143.04
UG Sorghum	1,995	$171.35	$54.04	$0.24	$259.12