ANALYZING ANIMAL DISEASE, STOCKER CATTLE PRODUCTION SYSTEMS, AND POLICY CHOICES IN PRODUCTION AGRICULTURE

A Dissertation

by

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DOCTOR OF PHILOSOPHY

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ABSTRACT

Agricultural producers across a diverse set of enterprises face significant risk each year when planting begins, livestock are purchased, or a new investment is made in machinery or facilities. Participants in other industries face risk from financial markets, global trends, and the preferences of customers. Unique to agriculture is risk from biologically-induced time-lags in production, climate variability, invasive species and pests, and disease in addition to the risks faced by other industries. Where some industries are able to spread risk over dozens, hundreds, even thousands of shareholders, the risk from working in production agricultural commonly accrues to a single nuclear family, or a small number of relatives.

Farm managers face different decisions daily, and a single choice can significantly impact profitability. The collection of research in the following essay models under widely different circumstances in which management must choose between options that represent significantly different levels of profitability.

The first essay included in this research estimates the cost of a Cattle Fever Tick eradication procedure in South Texas to an individual ranch and government agencies. The second essay estimates average daily gain in stocker enterprises based on different levels of days on pasture, stocking rate, and supplementation, and determines whether days on pasture are significantly impacted by changing temperature and precipitation. The third essay determines the value of a theoretical mix of the agricultural revenue coverage (ARC) and price loss coverage (PLC) programs.

DEDICATION

Galatians 6:9. And let us not grow weary of doing good, for in due season we will reap, if we do not give up.

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I would like to thank my friends and coworkers for their constant support. Finally, I want to thank my family and especially my mom for her constant encouragement and help.

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CHAPTER I INTRODUCTION

THE COST OF A CATTLE FEVER TICK ERADICATION

Introduction

Cattle Fever Ticks (*rhipicephalus annulatus* and *rhipicephalus microplus*) (CFT) feed on cattle and other ungulates resulting in poor physical condition and reduced reproductive capacity. Additionally, CFT are a vector of *Babesia bovis*, a virulent species of Bovine babesiosis, commonly referred to as Cattle Fever. Cattle fever presents with anorexia, high fever, lack of appetite, weakness, immobility, diarrhea or constipation and damages the central nervous system which can lead to incoordination, teeth grinding and mania. In naïve cattle survival of cattle fever varies, however in fully susceptible breeds 50.0% or more of untreated animals and up to 10.0% of treated animals may die (Center for Food Security and Public Health, 2008). As the only vector of *Babesia bovis,* eliminating the CFT eliminates the possibility of infection.

Upon discovery of the CFT role in the spread of cattle fever in the late 1800s a systematic eradication protocol isolated the pest, within the U.S., to the Permanent Quarantine Zone (PQZ) along the Rio Grande in south Texas. The eradication of the [1]CFT is credited with the expansion and success of the U.S. livestock industry (Graham and Hourrigan, 1977). The eradication of the CFT left the U.S. livestock population

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[1] Part of the data reported in this chapter is reprinted with permission from "Integrated strategy for sustainable cattle fever tick eradication in USA is required to mitigate the impact of global change" by Perez de leon, Adalberto A., P.D. Teel, A.N. Auclair, M.T. Messenger, F.D. Guerrero, G. Schuster, and R.J. Miller, 2012. *Frontiers in Physiology*, 3, 1-17, Copyright [2012] by Creative Commons.

unexposed to cattle fever while it is still endemic in Mexico. Periodic infestations, both within and outside of the PQZ, lead to quarantine measures which lead to financial consequences for ranchers and government agencies.

The mortality of cattle fever poses significant financial hardship when it presents in a naïve cattle population. However, efforts to eradicate the CFT are also costly. Rule 41.8 “Dipping, Treatment, and Vaccination of Animals” of the Agriculture title of the Texas Administrative Code states, “The owner or caretaker is responsible for all costs associated with and labor necessary for presenting the owner or caretaker's cattle for scratch inspection, dipping, treatment, or vaccination at the location prescribed by the commission.”

In March 2016 Texas Animal Health Commission (TAHC) announced the quarantine of a premises in Live Oak County, over 100 miles outside of the PQZ, after a bull on the property was confirmed as a host of a CFT. As a result, TAHC established a Control Purpose Quarantine Area (CPQA) to systematically inspect all wildlife and livestock in the area of the infested premises. The ‘Live Oak County outbreak’ resulted in the quarantine and designation as ‘check-premises’ of over 60 properties that were home to various wildlife, over 4,000 head of cattle, and 200 horses. The Live Oak County outbreak prompted this research and will serve as a template for scaling ranch-level and agency-level costs of CFT eradication.

This study simulates a CFT infestation in a representative cattle herd, absent infection of cattle fever, and the resulting quarantine cost under different eradication options. The purpose of this study is to determine the cost of the different quarantine procedures to ranchers and state and federal animal health agencies using the effectiveness of each treatment to determine the number of treatments in combination with the cost of each treatment.

This study is the first simulation model to combine the life cycle of the CFT with the cost of each of four eradication protocols. Rather than obtaining the cost of a single round of quarantine procedure, this study utilizes the biology of the fever tick in combination with the effectiveness of eradication protocols to determine the estimated number of quarantine procedures necessary to eradicate a CFT infestation. The bioeconomic model used in this study can be extrapolated to similar infestations and can be used as a template for other disease or pest control cost estimations.

Literature Review

Cattle Fever Tick history

Cattle fever or Texas cattle fever has an extensively documented history. Inexplicably under-performing cattle in the southern United States compared to the north throughout the 1800s led to southern producers' frustration and confusion (Graham and Hourrigan, 1977; Haygood, 1986). Producers sought various solutions to improving their herds including importing high quality breeding stock from the north, however these animals died upon exposure to cattle fever (Graham and Hourrigan, 1977). Animals that survived to adulthood in the south were slow to mature and underperformed in carcass quality, breeding, and milking. In addition to the losses experienced from underperforming stock, southern producers suffered from bans on transport of animals to regions unexposed to the CFT.

When cattle were moved north, either by rail or by long-distance cattle drives, there was a common occurrence of sudden death in animals native to the northern areas upon exposure to southern cattle. The disease caused a mortality rate of more than 90.0% and, in some cases, 100.0% of the newly exposed cattle did not survive exposure (Haygood, 1986). The economic hardship caused by the high death loss led to the ban in certain states of southern cattle shipments.

A groundbreaking study in the fields of veterinary science and human medicine by Smith and Killborne (1893) conducted to ascertain the cause of Babesiosis proved arthropods serve as the vector for the disease in humans and animals. In 1906, shortly after Smith and Killborne authored their study the United States enacted the Cattle Fever Tick Eradication Program (CFTEP).

The CFTEP spanned the period from 1907 to 1943 and required the cooperation of state and federal governments and local producers (Perez de Leon et al., 2012; Giles et al., 2014). The effort began with surveys to determine the northern border of cattle fever followed by restrictions on the northward-movement of cattle from tick-infested areas during warm weather; an area including approximately 700,000 square miles below a line that began in Virginia and ended in Texas and parts of California. Finally, federal governments employed veterinary staff, whose numbers were supplemented by state and local governments in certain cases, to monitor cattle for parasites and counties constructed dipping vats to apply acaricide to animals (Graham and Hourrigan, 1977). Voluntary cooperation of producers was integral to the success of the program, although participation was not always voluntary or cooperative.

Figure 1 “Texas Cattle Fever Tick Range” (Perez de Leon et al., 2012) contains the range of the CFT prior to the CFTEP and the PQZ established along the Texas/Mexico border. By 1960 CFT were restricted to an area along the Texas-Mexico border that is strictly monitored by the Animal and Plant Health Inspection Service, Veterinary Services (APHIS-VS) and the Texas Animal Health Commission (Giles et al., 2014). Estimates of the losses incurred by the U.S. economy due to the presence of the CFT and the resulting Babesiosis range from $23,250,000 to $130,500,000 (Mohler, 1906; Harwood and James, 1969), and the CFT was widely considered as the major challenge in establishing a livestock market in the rural south.

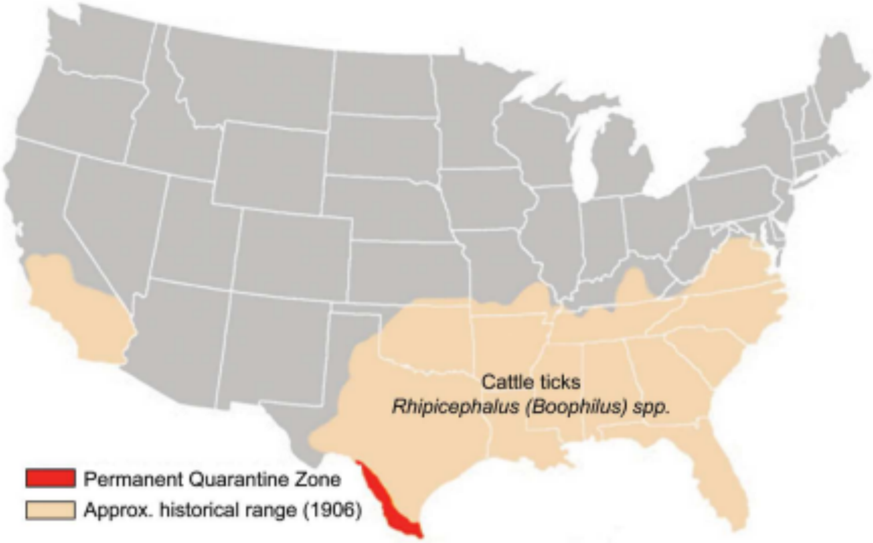

Figure 1. Texas Cattle Fever Tick range – Reprinted (Perez de leon et al., 2012)

Since the late 1940s infestation of the CFT have been primarily isolated in the PQZ with periodic outbreaks outside of the boundary. The ‘Live Oak County outbreak’ in April 2016 is the most recent infestation to occur outside of the PQZ.

Cattle Fever Tick biology

CFT spend the majority of their life off-host in the egg and larval stages, from six to nine months depending on the local microclimate (Graybill, 1911; Perez de leon et al., 2012). CFT are one-host parasites that complete their larval stage in vegetation in search of a passing host and upon attachment remain on a single animal from the larval to adult stage. (Mount et al., 1991; Davey et al., 1994). Adults mate and detach with females depositing approximately 3,500 eggs, again, dependent upon microclimate conditions before dying (Davey et al., 1994). Each year, approximately six generations of the species are completed (Mount et al., 1991).

Climate plays a role in the oviposition and general success of the CFT, and different environmental conditions may alter tick biology (Davey et al., 1980; Mount et al., 1991; Perez de Leon et al., 2012). Teel et al. (1996) found that seasonal changes in the environment produce two population constraints for the CFT; one is the result of cold temperatures during winter months and another from high-temperature and low-humidity-induced mortality. Numerous studies have also proven that individual pasture conditions and microclimate have a significant impact on the persistence of a CFT infestation (Teel et al., 1996; Teel et al., 1998; Teel et al., 2003; Corson et al., 2004). Additionally, global climate changes are a driver of geographic distribution of the CFT, specifically in northern Mexico and South Texas (Corson et al., 2004; Estrada-Pena et al., 2006; Estrada-Pena and Venzal, 2006).

The preferred host of the CFT are animals of the family *Bovidae* and, when the animals are present, CFT feed almost exclusively on domestic cattle (Anderson et al., 2008). Once a tick carrying *Babesia* transmits the pathogen to an animal it will exhibit fever, hemolytic anemia, hemoglobinuria and in many cases, death (Kuttler, 1998). Animals who do recover retain the infection and remain immune for long periods, and so act as vectors of the disease between ticks and other livestock themselves, and young animals are generally more tolerant than older animals (Jongejan and Uilenberg, 2004). Even when not acting as a disease vector ticks can cause direct harm to livestock, causing decreased productivity and poor health. Jongejan and Uilenberg (2004) describe an infestation of *Boophilus microplus* on the island of New Caledonia without introduction of diseases that have still necessitated intensive acaricidal treatment due to decreased productivity among *Bos taurus* on the island.

CFT will spread to other animals in the instance where cattle are unavailable (Kistner and Hayes, 1970; Cooksey et al., 1989; Perez de Leon et al., 2012; Bram et al., 2002; Pound et al., 2010; Cardenas-Canales et al., 2011; Busch et al., 2014). When cattle are unavailable, numerous ungulate species serve as a suitable host. The most common host that has overlapping habitat with cattle in south Texas is the white-tailed deer. (Kistner and Hayes, 1970; Busch et al., 2014) These animals host fewer ticks in similar environments, possibly due to their grooming habits, and fewer ticks complete engorgement (Cooksey et al., 1989) however the parasites are present. Kistner and Hays (1970) collected white-tailed deer from four estates on St. Croix of the U.S. Virgin Islands and collected CFT from multiple deer, including two infested with *B. (R.) microplus* in an area that had not been exposed to livestock for 20 years. More concerning than the presence of CFT, white-tailed deer were recently found to be sero-positive for *Babesia* in Texas and northern Mexico (Pound et al., 2010).

An additional problematic species that serves as a suitable host to CFT are the wild Nilgai antelope (*Boselaphus camelotragus*) of South Texas (Sheffield et al., 1983). Cardenas-Canales (2011) conducted a study on a private ranch in Coahuila, Mexico, from which cattle had been absent for ten years, in which they collected blood samples from 20 Nilgai. The authors indicated *Babesia*-positive animals, but, no ticks and concluded that Nilgai cannot be disregarded as a potential reservoir of bovine babesiosis. An additional issue presented by Nilgai are their large (up to 16.3 km) home ranges that regularly crosses borders from infested to non-infested areas (Moczygemba et al., 2012).

Wildlife and the Cattle Fever Tick

Wildlife complicate Cattle Fever Tick eradication efforts. Certain wildlife species, namely white-tailed deer (WTD) and nilgai, a large member of the family *Bovidae*, serve as reservoir species for CFT (Kistner and Hayes, 1970; Cooksey et al., 1989; Pound et al., 2010; Cardenas-Canales et al., 2011). There are methods in place to treat these species’ infestations, however there is no guarantee that all animals are treated.

There is evidence of stable tick populations with reduced productivity in WTD. White-tailed deer are widespread in south Texas (Currie, 2013; and serve as a suitable host for stable CFT populations (Currie, 2013; Perez de Leon et al., 2012) with reduced CFT population vitality (Currie, 2013). Cooksey et al. (1989) speculates that reduced CFT population vigor (fewer females fully engorged and reduced egg weight) results from WTD ability to better groom than cattle. Grooming as a form of disturbance interrupting the development of CFT is supported by Davey et al. (1980) in which ticks disturbed during development presented reduced weight and number of eggs compared to those ticks that were undisturbed.

Nilgai, a native of India and Pakistan were introduced to southern Texas during the early 1900s by the King Ranch for hunting (Moczygemba et al., 2012; Lohmeyer et al., 2018). The current number of nilgai in southern Texas is unknown, however by 1992 the population was estimated at over 37,000 and nilgai are now considered the area's most abundant free-ranging exotic ungulate (Traweek and Welch, 1992). Nilgai are similar in size and closely related to cattle making them a competent host for CFT. Nilgai do not congregate in similar numbers as WTD but their home ranges can exceed that of WTD by more than nine times (Moczygemba et al., 2012) and their ability to easily navigate high fences by jumping or pushing underneath them makes them a critical concern for the CFTEP (Lohmeyer et al., 2018).

The percent of infestations attributed to WTD and nilgai has been increasing over time. Lohmeyer et al. (2018) documented the number of new CFT infestations for fiscal years 2007-2009 and 2014-2016. Table 1 presents a summary of Lohmeyer et al. (2018) findings.

Table 1. Properties newly infested with the cattle fever tick infestations in South Texas for years 2007-2009 & 2014-2016 categorized by species of initial detection.

	Species		
Year	Cattle/Horses	WTD	Nilgai
2007	74	9	1
2008	106	24	0
2009	129	16	1
2014	21	6	0
2015	34	14	3
2016	61	18	8

During the two periods in Lohmeyer et al. (2018) there was a change in the percentage of infestations attributed to wildlife. The average percentage of infestations attributed to wildlife in the first three-year period was 14.0% while the average percentage of infestations attributed to wildlife in the second three-year period was 28.0%.

There are eradication methods available for CFT infestations in WTD. TAHC can install '2-poster' or '4-poster' feeding stations where feeding WTD are exposed to topical acaricides, which will be distributed by the animal during grooming, and feed ivermectin treated corn (Currie, 2013; Lohmeyer et al., 2018). Both methods have limitations inherent in WTD social structure. Larger more dominant bucks will spend more time at feeders than does and more submissive bucks and not all deer in an infested area will encounter a feeder (Currie, 2013). Currently, there are no methods available for treating CFT infestations on nilgai (Lohmeyer et al., 2018).

Consequences of a babesia bovis *outbreak*

The ultimate reason for eradicating the CFT, outside of concern for animal welfare, is the cost of *babesia* to the livestock industry. Prior to 1906 the United States attributed $130,500,000 to tick related losses (Harwood and James, 1969) with Graham and Hourrigan (1977) estimating that that sum would have exceeded $1 billion, 1976 dollars. Mohler (1906) estimated a loss in value of approximately $1 million annually for the southern cattle market due to the impacts of CFT-born *babesia*. Anderson et al. (2010) used representative ranch data developed and maintained by the Ag & Food Policy Center to estimate the cost of a CFT outbreak and found that an outbreak outside of the quarantine zone would cost an estimated $123 million in the first year, and about $97 million annually once capital costs were paid in the first year, exceeding current funding for the CFTEP. Additionally, Anderson et al. (2010) concluded that a 500 cow-calf ranch in Texas would incur a cost of $250 per cow leading to a 47 percent increase in expenses due to an infestation of CFT and that a property adjacent to the infested ranch would experience an increase in cash expenses of approximately eight percent with an associated 13 percent decrease in net cash income. Finally, they concluded that an outbreak extending to the historic range, encompassing much of the southeast, would result in a minimum cost of $1.2 billion in the first year to the livestock industry; a low estimate due to a lack of infrastructure in most southeastern states.

Eradication options of the Cattle Fever Tick

Treatments have evolved over time and there are now multiple options to consider when a CFT infestation occurs. Upon detection of an infestation producers and the TAHC will agree upon a prescribed system of applying a topical acaricide through dipping or spraying, vaccination, or vacating the infested pasture (4 TAC, §41.8, 4 TAC §41.9).

Systematic dipping in an authorized dipping vat in some form of acaricide has long been found to be the most effective method of eliminating CFT on an infested herd (Graham and Hourrigan, 1977; George, 2000; George et al., 2004). Dipping began in the late 19th century in response to anecdotal evidence that ticks were leading to widespread disease in cattle even prior to Smith and Killborne (1893) (Graham and Hourrigan, 1977). Figure 2 contains an example of a dipping or "plunge" vat design by Dr. Temple Grandin. Acaricide options have ranged widely since the begging of the effort to eradicate the CFT and have included oil, lime-sulphur, nicotine solutions, sodium sulphite and for approximately 60 years of the CFTEP, arsenic. (Graham and Hourrigan, 1977; George, 2000). Arsenic was eventually phased out as a result of the narrow limits between the effective concentration for control and the toxic level for cattle in favor of organic insecticides (Graham and Hourrigan, 1977).

Dipping occurs on the premises of the affected herd every seven to 14 days for six to nine months, with the schedule dependent upon the CFT life cycle. (Texas Cattle Fever Tick, 2017). The procedure is repeated until the pasture is 'clean' of CFT. Dipping has likely proved to be the most effective option because the ticks latch on to the animals and are killed during the dipping process, effectively removing them from the breeding population, animal by animal, over time. The most significant issue facing dipping is acaricide-resistance in CFT. Arsenic, the previously mentioned longstanding acaricide used by the CFTEP was phased out, in part, due to resistance issues (George, 2000;

George et al., 2004) and resistance to organophosphates currently in use remain a concern in the eradication of the CFT (George, 2000; George et al., 2004).

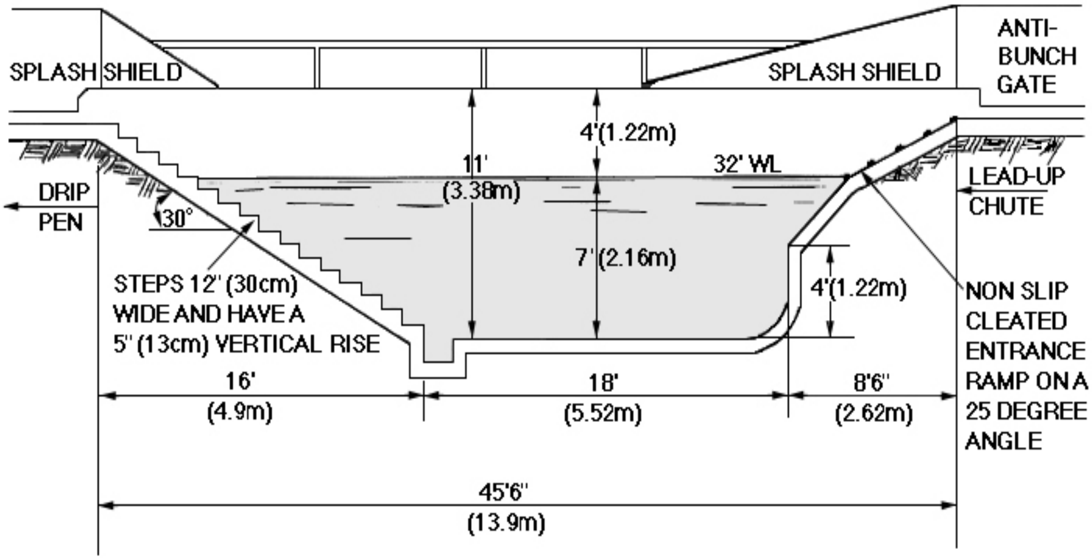

Figure 2. Dipping Vat Design – Reprinted (Grandin)

Topical acaricides can also be applied via a spray-dip machine where a vat is not reasonably available (4 TAC, §41.8). Under the direction of the TAHC animals are sprayed under the same schedule as the dipping protocol however they are moved through a portable ‘spray-box’, an enclosed chute with spray nozzles directed toward the animal from all directions. The nozzles emit an acaricide that, when applied correctly, provides the same efficacy as a dipping treatment[2].

A second option available to producers upon infestation is the opportunity to vacate a premises. Vacating operates under the idea that the ticks will be “starved out”

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[2] During summer 2018, the Texas Department of Agriculture Commissioner announced the discontinuation of the use of spray boxes in eradication efforts. As of writing, that situation is not resolved.

from removal of the host (Texas Cattle Fever Tick, 2017). Vacating can be more economical because producers do not repeatedly need to collect and transport cattle for dipping, however it is less effective likely due to habitat crossover with wildlife. Suitable hosts (WTD, nilgai) remain behind after the cattle are removed and serve as suitable hosts for CFT so that when the cattle return the ticks are still present (Texas Cattle Fever Tick, 2017).

The final option available when dealing with an infestation of CFT is series of recently developed vaccines. "The … cloning and expression of the Bm86 antigen in *Escherichia coli* and commercialization of the recombinant Bm86 anti-tick vaccine marketed as TickGUARD provides the first practical technology for use in an integrated approach to control *B. (R.) microplus*" (George, 2000). An additional product, Gavac, was developed in Cuba in 1993 (George, 2000; Miller et al., 2012). George (2000) speculates that efficacious vaccines may become a cost effective alternative for eradication of *B. (R.) microplus*. Miller et al. (2012) found overwhelming evidence supporting the use of vaccines in the effort to eradicate the CFT, reviewing multiple studies conducted in South and Central America and concluded that, "incorporating the practice of immunization, using a Bm86-based vaccine, to the existing protocol requiring the use of chemical acaricides would allow the elimination and prevention of outbreaks in the northwestern half (350 km) of the PQZ (Permanent Quarantine Zone) where *R. annulatus* is the predominant species," however results have not been as overwhelmingly successful with *R. microplus*.

As of September 2016 TAHC and APHIS have published procedures for use of a Bm86 immunomodulator by Zoetis as a new vaccine to target and kill both species of CFT within the quarantine zone (Texas Cattle Fever Tick, 2017). Under the use of the vaccine cattle receive an initial does, a booster four weeks later and an additional booster every six months indefinitely in order to maintain the concentration of antibodies for effective treatment (Texas Cattle Fever Tick, 2017). Each treatment option presents a different level of efficacy when eradicating a CFT infestation (Table 2).

Table 2. Characteristics of Cattle Fever Tick eradication options.

Eradication option	Efficacy	Frequency of administration	Duration of treatment
Injectable BM86	45.0%	Initial dose, booster 1 month after initial dose, booster every 6 months after first booster	Initial dose - perpetuity
Acaracide dip	97.0%	Every 7-14 days	6-9 months
Acaricide application in spray box	97.0%	Every 7-14 days	6-9 months
Pasture vacation*	0-97%	Continuous	6-9 months

*The efficacy of pasture vacation is highly variable and dependent upon presence of variety and density of wildlife

Data and Methodology

Model development

The study utilizes a simulation model in a compartment modeling software with a daily time step over ten years to evaluate the cost of a fever tick outbreak by iteratively conducting the quarantine and life-cycle processes and evaluating the impact of a chosen policy. The model conducts 1,000 iterations of the simulation which are used to obtain average and standard deviations of the cost of each policy choice given its treatment efficacy.

This research makes several assumptions. Following Anderson et al. (2010), the study assumes a herd size of 200 head with an average weight of 1,100 lbs. per animal, based on an Agriculture and Food Policy Center (AFPC) representative ranch based in Gonzales County, Texas. The representative ranch consists of 900 acres located approximately 100 miles from the location of the 2016 'Live Oak County outbreak' in a similar habitat. The model is initiated by introducing 115 adult fever ticks into the system representing a theoretic infested animal that passed undetected. The number of fever ticks was chosen based on Teel et al. (2003) in which the authors establish a best, average, and worst case scenario of detecting a CFT infestation. In an average case 115 CFT represents approximately a 50.0% chance of detection (Teel et al., 2003). Additionally, in all cases where CFT population dynamics are influenced by habitat and/or microclimate, the model assumed a mixed-brush environment under average climatic conditions.

STELLA

STELLA (short for Systems Thinking, Experimental Learning Laboratory with Animation) is a visual programming language for systems dynamics modeling, and is used in a variety of modeling practices. STELLA uses a system of graphically represented stocks, flows, converters, and connectors to develop dynamic simulations. STELLA has been used extensively to model Cattle Fever Tick population dynamics and movement (Teel et al., 1998; Teel et al., 1996; Teel et al., 2003; Corson et al., 2004). STELLA can conduct a dynamic simulation with a specified number of iterations in order to obtain an "average case" scenario over a distribution of variables.

The population dynamics of Cattle Fever Ticks are modeled similarly to previous studies. The contribution to the literature, and modeling efforts involve incorporating a dynamic representation of the possible eradication procedures into a system model with tick life-cycle dynamics.

Figure 3 is the graphic representation of the bioeconomic model used to estimate the cost of eradicating a CFT outbreak. Squares represent stock variables, circles represent converter variables (used for multiplication and the introduction of seasonality), blue ‘valves’ represent flows, and red arrows represent connectors, used to create interaction between the other variable types.

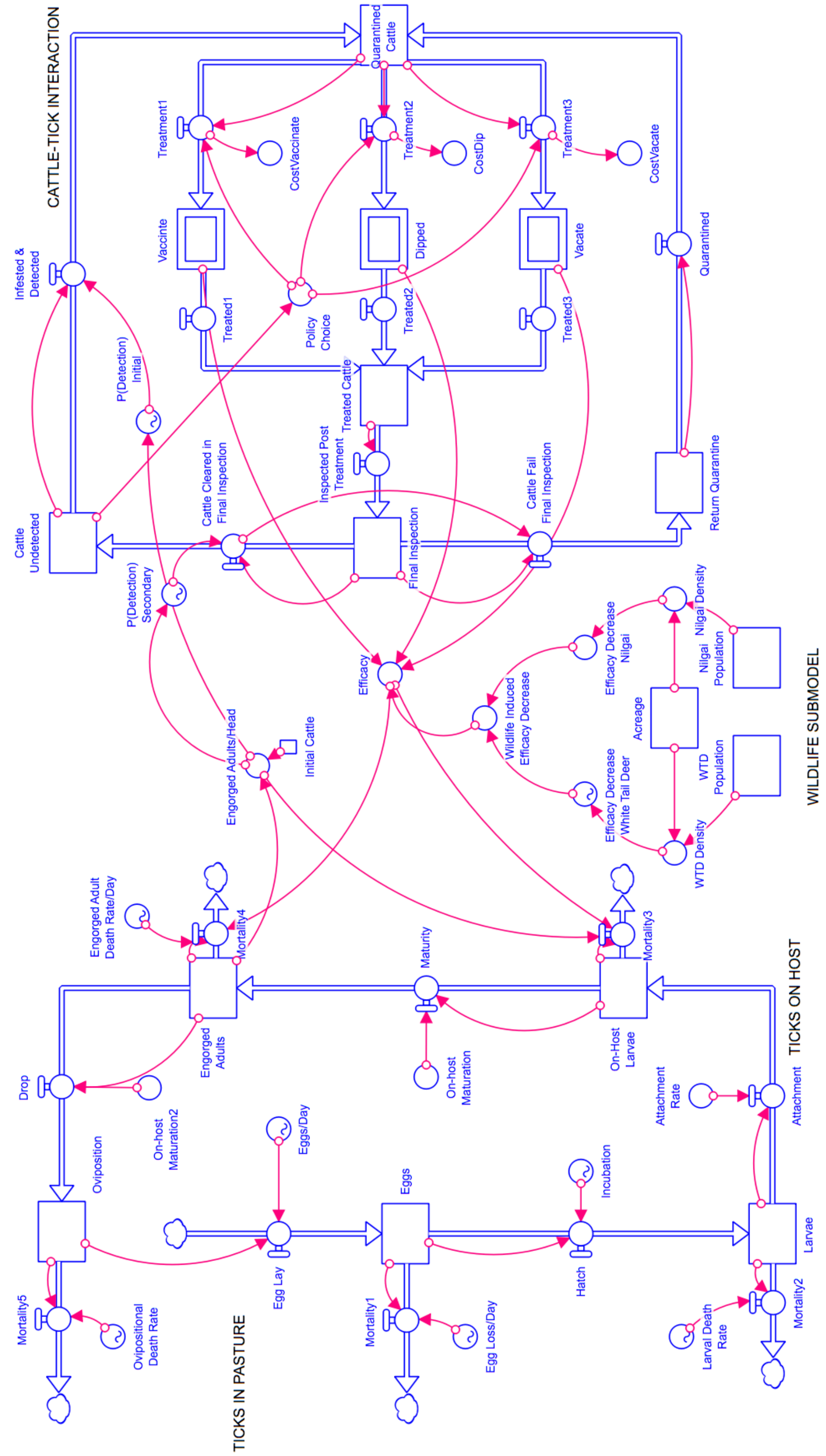


Figure 3. Graphic representation of STELLA compartment simulation model

Cost of treatment strategies - Ranch

Each eradication option poses a different set of costs to the rancher. The rancher is responsible for costs associated with presenting the animals for inspection and treatment. Costs of presenting animals are developed from the 2016 Texas Custom Rate Survey using the ‘South’ category, representing the region commonly infested with CFT. An additional employee is required for every 100 head of cattle quarantined and the need to repair 100 feet of steel t-post fence, once at the end of the quarantine, in all eradication options.

For cattle dipping off the premises, the model assumes the cost of additional labor for gathering and processing cattle each time a treatment is required during a quarantine, fencing repair from increased use, and hauling cattle to and from the dipping site. Dipping under a single six to nine month quarantine will require treatments once every seven to 14 days depending on the protocol chosen by the rancher and TAHC. In addition to the cost of additional employees and fence repair, dipping off-site incurs a cost of hauling. Hauling 200, 1,100 lb. animals requires five semi-truck loads based on a 50,000 maximum weight. The model assumes that the animals must be transported approximately 50 miles to an in-ground dipping vat and the cost of hauling the animals each time was taken from the 2016 Texas Custom Rate Survey ‘South’ category for semi hauling.

For dipping, spraying, and vaccinating on-site the model assumes the cost of additional labor for gathering and processing cattle each time a treatment is required during a quarantine and fencing repair from increased use. Dipping and spraying under a single quarantine will require six to nine months of treatment depending on the protocol chosen by the rancher and TAHC, and the BM86 vaccine will require boosters indefinitely.

For vacating a pasture, the model assumes the cost of additional labor for gathering and processing cattle for two on-site dipping procedures and the cost of transporting the animals. Hauling 200, 1,100 lb. animals requires 5 semi-truck loads based on a 50,000-maximum weight. The model assumes that the animals must be transported approximately 100 miles to available pasture and the cost of hauling the animals was taken from the 2016 Texas Custom Rate Survey 'South' category for semi hauling. Unique to the pasture vacation option is the need to rent additional grazing for the duration of a quarantine. NASS survey data for the year 2016 for pastureland rent for the Coastal Bend, Lower Valley, South Central, and South Texas Agricultural Districts was used to compute an average cost per acre of rented pastureland. The average cost of pastureland from one animal unit per ten acres to one animal unit per twenty acres was averaged inn order to incorporate a variable stocking rate.

Table 2 contains the average cost of each eradication option per six to nine month quarantine. The frequency and duration of treatments required varies based on TAHC and rancher established plans, representing a varying total average cost within the same eradication option. The costs per quarantine are multiplied by the number of quarantines necessary to eradicate a population per iteration of the model.

Table 3. Average cost to rancher of each eradication option per quarantine.

	Day-labor	Fencing repair	Hauling (50 mi)	Pasture rent	Cost/Quarantine	
Eradication Option	Average/ treatment	Average total cost	Average/ treatment	Average/ Acre	Average Total	Std. Dev.
Dipping off-premises	$334.00	$5,387.50	$783.20	NA	$28,848	$2,413
Vaccination	$334.00	$5,387.50	NA	NA	$7,892	$431
Dipping/spraying on-premises	$334.00	$5,387.50	NA	NA	$7,892	$431
Vacating	$334.00	NA	$783.20	$8.35	$18,787	$4,154

Cost of treatment strategies – Agencies

While the rancher is financially responsible for presenting cattle for treatment and for any damages to their property that occur from increased use, TAHC and APHIS share the cost of providing treatment for the infested livestock. Table 4 contains the spending categories by TAHC and APHIS when a quarantine is enacted. Wildlife feeders are placed under all quarantine procedures. Expenses that are incurred each time a quarantine is enacted are delineated by an X in the 'Recurring Expense' column.

Using the information provided by TAHC and the nature of each type of expense (recurring versus one-time) this study estimates the cost to government agencies of each type of eradication procedure each time a quarantine is enforced. Table 4 lists the estimated costs of each eradication strategy in its first year and subsequent years based on the recurring expense list in Table 4.

Outbreak-specific costs, designated with an "X" are costs that occur annually and depend on the individual outbreak. Other expenditures are capital outlays that can be purchased once, generally at the onset of the outbreak. The costs in Table 4 only represent an estimate of costs and could change based on the number of “check” and “adjacent” premises caused by an outbreak.

Table 4. Categories of spending outlays by TAHC and APHIS under select quarantine procedures.

Wildlife Feeders	Outbreak - specific	Cost	*Submersion Vat*	Outbreak - specific	Cost
Feeders		$ 50,000	*Temporary in-ground vat facility		$ 80,000
Panels (6/station)		$ 28,980	*Permanent vat facility		
Posts (12/station)		$ 10,104	Scratching chute (10 panels)		$ 9,450
Corn	X	$ 91,375	Personnel	X	
Ivermectin	X	$ 4,730	Overtime (5 hours/week)	X	$ 9,070
Storage bin (22 ton)		$ 10,000	Equipment and supplies		
Feeder filling equipment		$ 14,000	Property plant and equipment	X	$ 3,000
Travel expense	X	$ 63,000	Cholinesterase testing	X	$ 5,200
Overtime	X	$ 9,208	Sprayer		$ 1,700
Personnel (1/100 feeders)	X	$ 77,000	Air compressor		$ 800
Trucks		$ 78,000	Utilities	X	
Fuel expense	X	$ 20,800	Generator	X	$ 3,500
Overtime (5 hours/week)	X	$ 21,767	Storage container		$ 2,500
Equipment and supplies	X	$ 30,000	Office		$ 4,500
Cholinesterase testing	X	$ 5,200	Fuel and miscellaneous	X	$ 5,000
Property plant and equipment	X	$ 3,000	CoRal Remediation/disposal	X	
Spray Box/Vaccination	Outbreak - specific	Cost	*Payroll*	Outbreak - specific	Cost
Travel expense	X	$ 157,500	Supervisor	X	$ 79,170
Overtime (rotating positions)	X	$ 23,019	Financial services staff	X	$ 13,094
Personnel	X	$ 192,500	Staff services	X	$ 52,780
Trucks		$ 195,000	IT staff	X	$ 26,390
Overtime	X	$ 22,674	Administrative staff	X	$ 38,570
Equipment and supplies		$ 75,000	Legal/compliance	X	$ 11,419
Fuel expense	X	$ 50,000	Epidimiologist (EPI)	X	$ 45,675
Sprayers		$ 8,500	Equipment and supplies	X	$ 68,250
Property plant and equipment	X	$ 7,500	Trucks - supervisor		$ 39,000
Cholinesterase testing	X	$ 13,000	Fuel expense	X	$ 10,400
Spray box			Travel - supervisor/EPI/legal	X	$ 24,000
Scratch chute		$ 18,900			
Panels w/ trailer		$ 2,600			
OK Corral		$ 12,000			
Recovery tank		$ 7,400			
Water tank (500 gallon trailer)		$ 12,800			
Dectomax	X	$ 75,000			
BM86 Vaccine	X	$ 16,800			
RFID Tag	X	$ 294			
RFID Reader		$ 1,500			
Miscellaneous	X	$ 2,500			

*Only one of the options is used on a given property

Outbreak specific costs exceed capital costs annually. Table 5 shows that annual agency costs are higher for dipping off-premises than for the other two strategies, except for vaccination capital expenditures.

Table 5. Estimated TAHC and APHIS combined agency cost under different eradication strategies.

	Eradication Strategy		
Year	Dip (off-premises)	Vaccine	Vacate
Year 1; capital expenditures and outbreak-specific expenditures	$1,870,018	$1,828,799	$956,305
Year 1 + n; outbreak-specific expenditures	$1,406,990	$1,189,721	$705,527

Efficacy

Each eradication option is associated with a different efficacy in eradicating a CFT infestation. A protocol of systematic dipping off-site or spraying or dipping on-site is associated with an efficacy of 97.0%, the required efficacy of all acaricides allowed under the Texas Administrative Code (4 TAC, §41.8). TAHC officials are required to administer or be present for the administration of any topical acaricide applied due to a CFT infestation, so the model does not assume any reduction in effectiveness due to improper application.

Preliminary research presented on the CFT vaccine shows an efficacy of 45.0% in *R. microplus* and 99.0% in *R. annulatus* (Hasel, 2016). The vaccine must be administered under the supervision of TAHC professionals, and based on the species of CFT in infestation outside of the PQZ (*R. microplus*) the model assumes an efficacy of 45.0%.

Efficacy of vacating pastures is the most variable of the eradication options available and is highly dependent upon the presence of wildlife. Vacating pastures in the absence of ungulate wildlife yields an efficacy of 97.0%. The residual 3.0% survival is representative of untreated reservoir WTD. The decrease in efficacy from the presence of wildlife is discussed further in the 'Wildlife Sub-model' section of this study.

Tick sub-model

This sub-model tracks the life cycle of the CFT population introduced into the representative ranch. The infestation is initiated in the state variable ENGORGED_ADULTS by introducing 115 adult CFT. The individuals in ENGORGED_ADULTS move via mortality or dropping. Daily mortality of individuals in ENGORGED_ADULTS is a function of the number of individuals in ENGORGED_ADULTS and a seasonally adjusted death rate (Teel et al., 1996):

$$\begin{aligned} &MORTALITY\ OF\ ENGORGED\ ADULTS \\ &\quad = ENGORGED\ ADULTS \\ &\quad * \begin{cases} SEASONAL\ DEATH\ RATE\ if\ EFFICACY < 0.05 \\ EFFICACY\ if\ EFFICACY > 0.05 \end{cases} \end{aligned} \tag{1}$$

Daily drop of individuals in ENGORGED_ADULTS is a function of the number in ENGORGED_ADULTS and the duration of time adult age ticks spend feeding, or a 'time to drop' rate ($\bar{x}$=0.036, σ=0.01) representing an average 28 day time to maturation (Hitchcock, 1955a).

$$DROP = ENGORGED\ ADULTS * RATE\ OF\ DROP \tag{2}$$

Individuals in ENGORGED_ADULTS move into OVIPOSITION via drop in which female individuals lay eggs. Individuals exit OVIPOSITION via final seasonally adjusted mortality in which all individuals exit the system (Hitchcock, 1955b):

$$\begin{aligned} &MORTALITY\ OF\ OVIPOSITION \\ &\qquad = OVIPOSITION * SEASONAL\ DEATH\ RATE \end{aligned} \tag{3}$$

The number of eggs in the EGGS state variable is dictated by the number of individuals in the OVIPOSITION state variable, a seasonal adjustment factor, and an adjustment for the male/female population ratio (Teel et al., 1996):

$$EGG\ LAY = OVIPOSITION * SEASONAL\ EGGS/DAY \tag{4}$$

Individual eggs in EGGS move via mortality or hatching. Daily mortality of individual eggs in EGGS is a function of the number of eggs in EGGS and a seasonally adjusted EGG_LOSS/DAY (Teel et al., 1996):

$$MORTALITY\ OF\ EGGS = EGGS * SEASONAL\ EGG\ LOSS/DAY \tag{5}$$

Daily hatch of individuals in EGGS is a function of the number of eggs in EGGS and a seasonally delayed incubation period (Hitchcock 1955b; Teel et al., 1996):

$$HATCH = EGGS * SEASONAL\ INCUBATION\ LENGTH \tag{6}$$

Upon hatching individuals move from EGGS to LARVAE. Individuals move out of LARVAE via mortality and attachment to a host. Daily mortality of individuals in LARVAE is a function of the number of individuals in LARVAE and a seasonally adjusted LARVAL_DEATH_RATE/DAY (Teel et al., 1996):

$$\begin{aligned} &MORTALITY\ OF\ LARVAE\ OFF\ HOST \\ &\qquad = LARVAE * LARVAL\ DEATH\ RATE/DAY \end{aligned} \tag{7}$$

Daily attachment of larvae is a function of LARVAE and a theoretic attachment rate. Information on attachment rates is not well documented, however previous attempts at modeling attachment do exist (Mount et al., 1991; Teel et al., 1996). This study follows the method established by Teel et al. (1996) in which there is a theoretic encounter rate with an associated pickup rate combined to yield a final attachment rate. This study assumes a constant pickup rate of 50.0% and tests three encounter rates of 0.004, 0.005, and 0.006, previously used by Teel et al. (1996), the combination of which yields attachment rates equal to 0.002, 0.0025, and 0.003. The daily attachment of larvae to a host is:

$$ATTACHMENT = LARVAE * ATTACHMENT\ RATE \tag{8}$$

Upon attachment larvae move from LARVAE to ON-HOST_LARVAE. Individuals move out of ON-HOST_LARVAE via mortality or maturity to engorged adult. Daily mortality of individuals in ON-HOST_LARVAE is a function of the number of individuals in ON-HOST_LARVAE and a death rate presented by Hitchcock (1955a) (x̄=.2106, σ=.065). Hitchcock (1955a) suggests no seasonality impacts on this life stage of the CFT as larval survival on host is not driven by climatic conditions. Mortality of ON-HOST_LARVAE is:

$$\begin{aligned} MORTALITY\ OF\ ON\ HOST\ LARVAE \\ = ON\ HOST\ LARVAE \\ * \begin{cases} NORM{\sim}(0.2106, 0.065) < 0.05 \\ EFFICACY\ if\ EFFICACY > 0.05 \end{cases} \end{aligned} \tag{9}$$

EFFICACY is described in the ‘Sub-model Interaction’ section Individuals that survive move from ON-HOST_LARVAE to ENGORGED_ADULTS via maturity, a function of ON-HOST_LARVAVE and an on-host maturation rate that accounts for the duration to maturity of the CFT on-host. Hitchcock (1955a) reports a maturation duration of ($\bar{x}$=0.067, σ=0.038) representing an average time to fully mature of 15 days prior to beginning engorgement. Movement of individuals from ON-HOST_LARVAE to ENGORGED_ADULTS is:

$$MATURITY = ON\ HOST\ LARVAE \\ * ON\ HOST\ MATURATION\ RATE \tag{10}$$

Movement of on-host larvae from ON-HOST_LARVAE to ENGORGED_ADULTS represents the beginning of next iteration of the population represented beginning in Equation (1) and Equation (2).

Cattle quarantine sub-model

The AFPC representative ranch in Gonzales owned 200 head of cattle in 2010 (Anderson et al., 2010), therefore the model initiates with 200 head of cattle in the state variable, CATTLE_UNDETECTED. Texas Animal Health Commission estimated that 4,000 beef cattle and 200 horses were quarantined over 200 individual premises as a result of the Live Oak county outbreak, however TAHC did not provide an 'average herd size' estimate. This research assumes that the ranch examined derives the majority of it's income on-farm, and therefore assumes a slightly larger herd size (200 head) than would be derived from simple division of the figures provided by TAHC.

Upon detection of a CFT infestation, driven by the population dynamics of the tick sub-model, cattle transition from CATTLE_UNDETECTED to QUARANTINED_CATTLE via an infestation and detection check.

$$\begin{aligned} &INFESTED\ \&\ DETECTED \\ &\qquad = P(DETECTION)INITIAL \\ &\qquad * CATTLE\ UNDETECTED\ HERD \end{aligned} \tag{11}$$

P(DETECTION)_INITIAL will be further described in the 'Sub-model Interaction' section. Upon the cattle reaching quarantine the individuals can move, as a unit, through one of three quarantine procedures, VACCINATE, DIP, or VACATE via selection of treatments:

$$VACCINATE = QUARANTINED\ CATTLE * \begin{cases} 1\ if\ VACCINATE \\ 0\ if\ OTHER \end{cases} \tag{12}$$

$$DIP = QUARANTINED\ CATTLE * \begin{cases} 1\ if\ DIP \\ 0\ if\ OTHER \end{cases} \tag{13}$$

$$VACATE = QUARANTINED\ CATTLE * \begin{cases} 1\ if\ VACATE \\ 0\ if\ OTHER \end{cases} \tag{14}$$

The policy choice is selected by the user. VACCINATE serves as a placeholder for vaccination, spraying, and dipping on the ranchers premises and efficacy of the treatment adjusted based on the user's treatment assumption. Each time cattle move from CATTLE_UNDETECTED into one of the quarantine procedures the model assesses the cost described for that strategy per the description in 'Cost of Treatment Strategies'. Each treatment is associated with a prescribed delay function of 225 days based on the length of treatment required (Texas Cattle Fever Tick, 2017). When the 225 day delay is complete the cattle move from their chosen treatment into the FINAL_INSPECTION state variable.

Individuals move out of FINAL_INSPECTION by either moving back to CATTLE_UNDETECTED or RETURN_QUARANTINE. Individuals are cleared through final inspection via:

$$\begin{aligned} &CATTLE\ CLEAR\ IN\ FINAL\ INSPECTION \\ &= FINAL\ INSPECTION \\ &* \begin{cases} 1\ if\ P(DETECTION)SECONDARY < 0.1 \\ 0\ if\ P(DETECTION)SECONDARY > 0.1 \end{cases} \end{aligned} \tag{15}$$

CATTLE_CLEARED_IN_FINAL_INSPECTION represents cattle inspected with a CFT population low enough that <10.0% of inspections, shown by Teel et al. (2003) as an inflection point of detection in all worst, average, and best cases, would detect CFT presence. P(DETECTION)SECONDARY will be further described in the 'Sub-model Interaction' section.

Cattle can also move via failed inspection to RETURN_QUARANTINE, subject to the outcome of Equation (15):

$$\begin{aligned} &RETURN\ QUARANTINE \\ &= FINAL\ INSPECTION \\ &* \begin{cases} 1\ if\ CATTLE\ CLEAR\ IN\ FINAL\ INSPECTION = 0 \\ 0\ if\ OTHER \end{cases} \end{aligned} \tag{16}$$

Wildlife interaction sub-model

The presence of wildlife on CFT infested property confounds eradication efforts (Pound et al., 2010; Lohmeyer et al., 2018), particularly when pasture vacation is used alone. This study incorporates a sensitivity analysis of the impact of different wildlife densities on vacated pastures as a CFT eradication strategy. WTD and nilgai are the primary alternative hosts of interest and so this study incorporates populations of each species.

Deer and nilgai density is the driver of decreased efficacy of vacating pastures. Deer density and nilgai density are a function of the WTD_POPULATION and NILGAI_POPULATION state variables, respectively, and the ACREAGE state variable which accounts for the size of the property quarantined:

$$WTD\ DENSITY = \frac{WTD\ POPULATION}{ACREAGE} \tag{17}$$

$$NILGAI\ DENSITY = \frac{NILGAI\ POPULATION}{ACREAGE} \tag{18}$$

Currie (2013) describes an average deer density in pastureland of southern Texas of approximately one deer per ten acres. Cooksey et al. (1989) indicates that deer can carry approximately one-tenth the CFT population of cattle due to smaller size and better ability to groom. Based on these assumptions the model assumes that a 50.0% increase in deer density decreases efficacy of vacating a pasture by 10.0%:

$$\begin{aligned} &WTD\ EFFICACY\ DECREASE \\ &\quad = .1 + 0.05 * \begin{cases} 1\ if\ WTD\ DENSITY > 1.5 * 0.1 \\ 0\ if\ WTD\ DENSITY < 1.5 * 0.1 \end{cases} \end{aligned} \tag{19}$$

Little study exists on the carrying capacity of CFT in nilgai, however they are similar in size and grooming ability to cattle, yet daily move across a wider range. Moczygemba et al. (2012) studied the home range of nilgai in southern Texas and found that males have an average home range of 9,356 ha. (23,120 acres) and females have an average home range of 8,355 ha. (20,646 acres). This study assumes a normal distribution of nilgai home ranges (x̄=5, σ=2) crossing the 900 acre pasture.

Based on the nilgai's wide range and constant movement (Moczygemba et al., 2012) their probability of encountering CFT is lower than that of cattle, however based on nilgai's similar grooming habits to cattle the model assumes that once CFT attach they are likely to remain. Efficacy decrease from nilgai is a function of the number of nilgai present in the pasture on any day. Each nilgai present in the system decreases efficacy by 2.5% as function of the density compared to cattle:

$$NILGAI\ EFFICACY\ DECREASE = NILGAI\ POPULATION * .025 \tag{20}$$

WILDLIFE_EFFICACY_DECREASE reduces EFFICACY and is a function of NILGAI_EFFICACY_DECREASE in Equation (20) and WTD_EFFICACY_DECREASE in Equation (19). EFFICACY is described further in the 'Sub-model Interaction' section.

Sub-model interaction

The interaction of the different sub-models drives the overall results. POLICY_CHOICE is a user input and allows for the choice of eradication strategy, which is enacted when cattle leave the CATTLE_UNDETECTED state variable. EFFICACY is the effectiveness of each eradication strategy in eliminating the CFT infestation, and is the major point of interaction for all three sub-models:

$$EFFICACY = \begin{cases} 0.45 \ if \ VACCINATE > 0 \\ 0.97 \ if \ DIP > 0 \\ (0.97 - WILDLIFE \ EFFICACY \ DECREASE) \ if \ VACATE > 0 \end{cases} \tag{21}$$

Based upon the user input in POLICY_CHOICE, the model assumes one of the listed eradication strategies and adjusts the VACATE efficacy based on the outcome of Equation (20). EFFICACY then acts upon Equation (1) and Equation (9) when above the prescribed value.

Three variables interact to determine probabilities of detection when CFT are present in the system. ENGORGED_ADULTS/HEAD is a function of the number of cattle assumed by the model and the number of engorged adult CFT present in the system:

$$\frac{ENGORGED \ ADULTS}{HEAD} = \frac{ENGORGED \ ADULTS}{NUMBER \ CATTLE} \tag{22}$$

ENGORGED_ADULTS/HEAD is the exogenous variable acting upon P(DETECTION)_INITIAL and P(DETECTION) _SECONDARY. Teel et al. (2003) described the human factors that affect the probability of detecting a CFT infestation in different circumstances. Figure 3 from Teel et al. (2003) describes a best, average, and worst case scenario of detecting adult CFT based on the number of detectable ticks (ENGORGED_ADULTS) per cow.

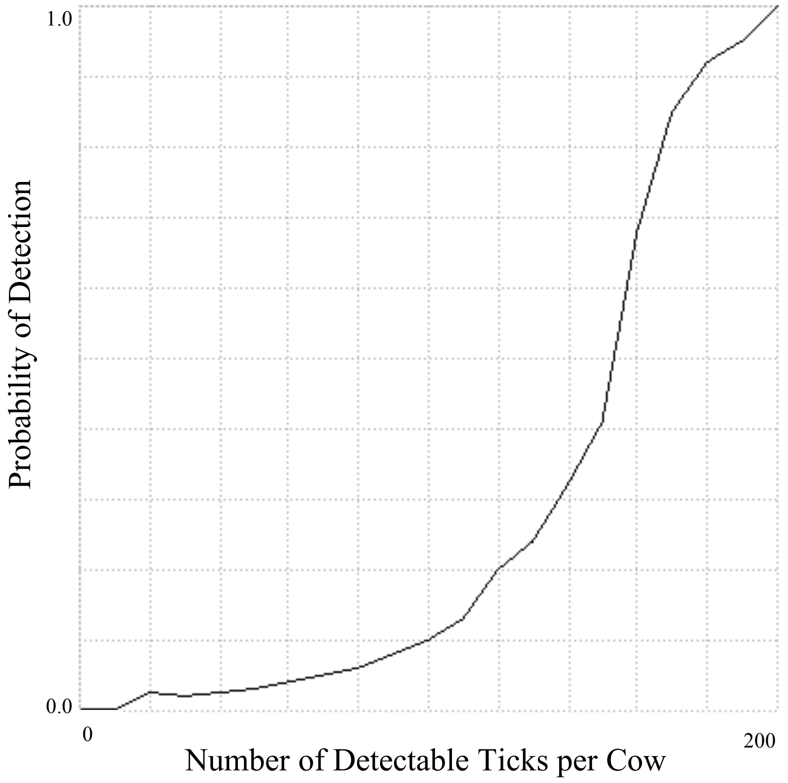


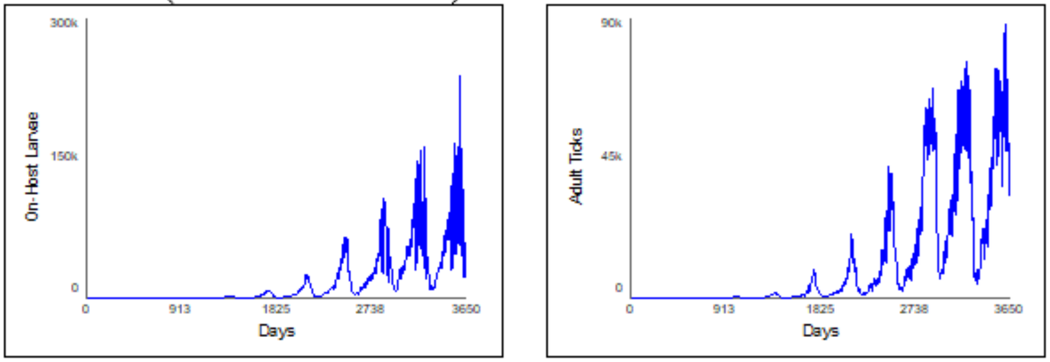
Figure 4. Probabilities of detecting at least one tick on a cow as a function of the number of ticks of a detectable size

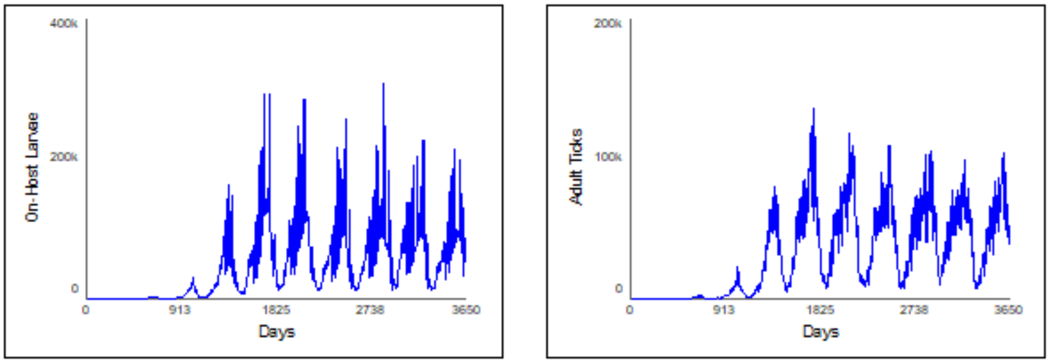
P(DETECTION)_INITIAL is based on the worst-case detection curve. Prior to detection of a CFT infestation ranchers are not as likely to observe and report an infestation. P(DETECTION)_INITIAL acts upon Equation (11) to initiate the quarantine process in the 'Cattle Quarantine' sub-model. P(DETECTION)_SECONDARY is based on the best-case detection curve. Once a quarantine has been initiated the model assumes TAHC inspectors and ranchers will conduct more thorough inspections. P(DETECTION)_SECONDAY acts upon Equation (15) to move cattle either back into quarantine procedure or into the initial CATTLE_UNDETECTED state variable.

Results

Each eradication procedure is associated with a different cost per quarantine as well as an estimated number of quarantine based on the probability of detecting a CFT infestation.

Figure 5 – Figure 8 each show a graph of a single iteration of the tick population models under different eradication procedures, and different attachment rates. Regular increases and decreases over time show the seasonality of tick population dynamics, where populations decrease due to excessive summer heat or extreme cold. A spike in population, followed by a rapid population decrease, represents a tick detection and subsequent eradication effort.


No treatment (Attachment rate = 0.002)


No treatment (Attachment rate = 0.0025)

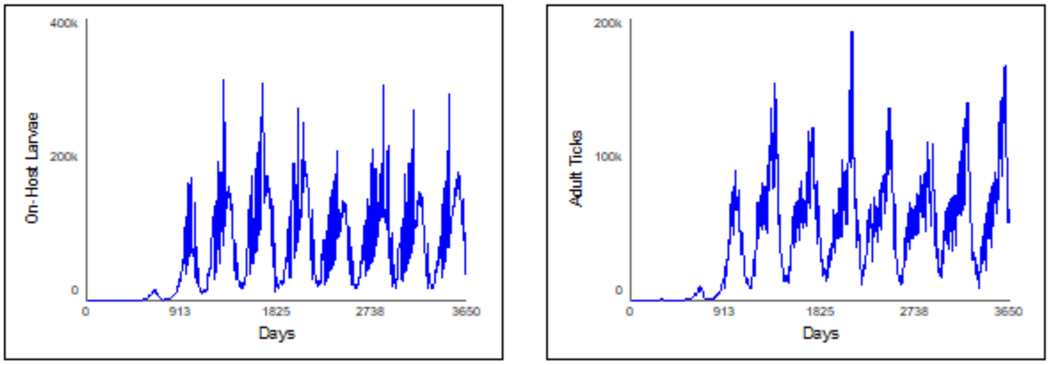

No treatment (Attachment rate = 0.003)

Figure 5. On-host larvae and adult tick population dynamics with no treatment[3]

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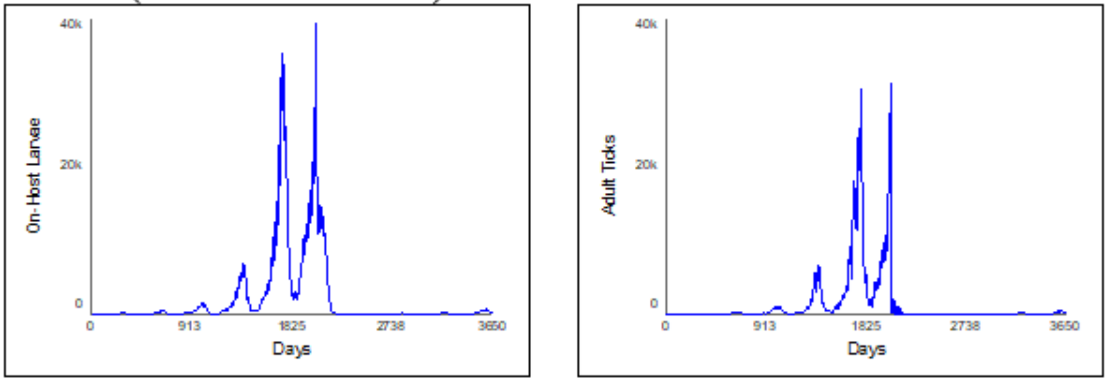
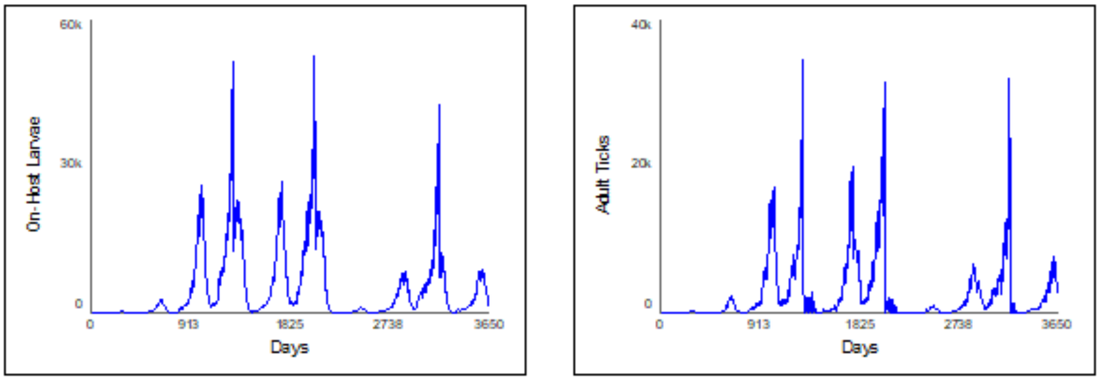
[3] Figure 5 – Figure 8 represent a single iteration of the Cattle Fever Tick ranch level model. Only one iteration was included to make the figures clear. Showing all iterations overlaid did not provide a clear representation of the tick populations under eradication protocols. The final iteration of the model was chosen for representation in Figure 5 – Figure 8. Other iterations may show different timing of tick population expansion and decrease, however the patterns of seasonality and response to eradication are similar in nature.

Vaccinate (Attachment rate = 0.002)



Vaccinate (Attachment rate = 0.0025)



Vaccinate (Attachment rate = 0.003)

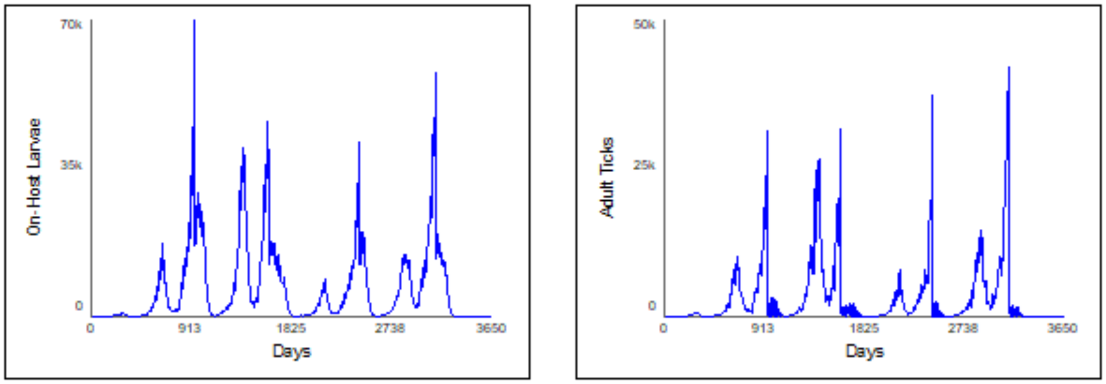
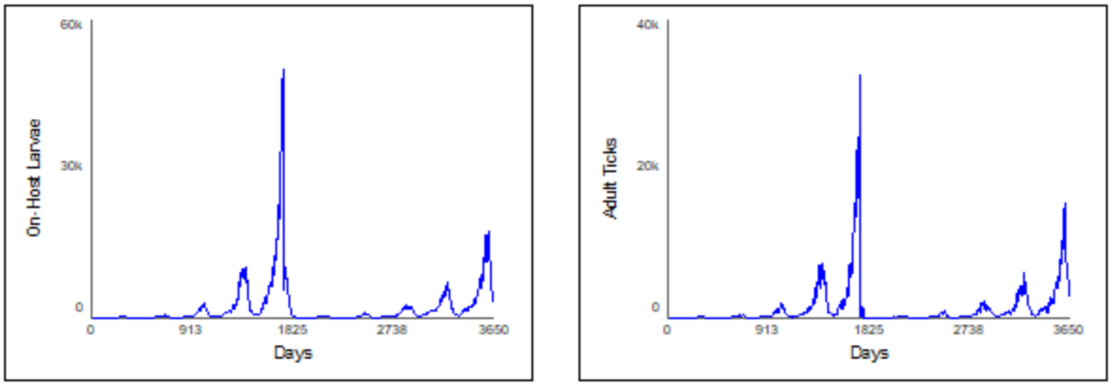
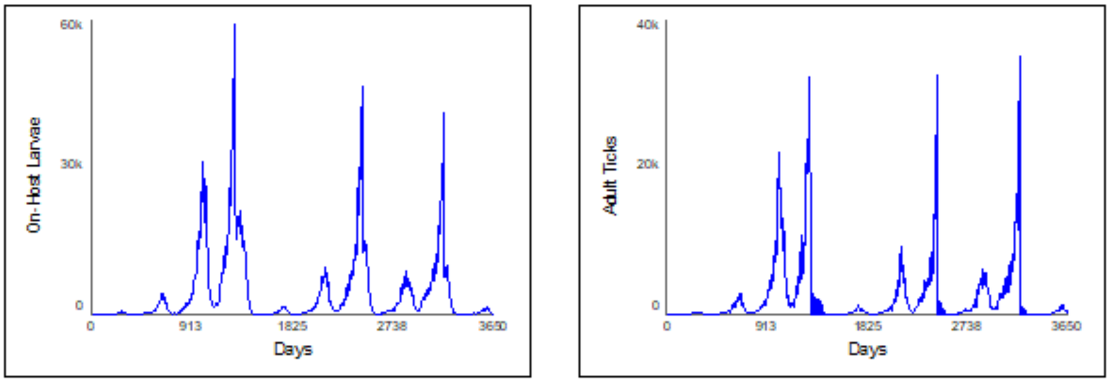


Figure 6. On-host larvae and adult tick population dynamics treated with vaccination

Dipping (Attachment rate = 0.002)



Dipping (Attachment rate = 0.0025)



Dipping (Attachment rate = 0.003)

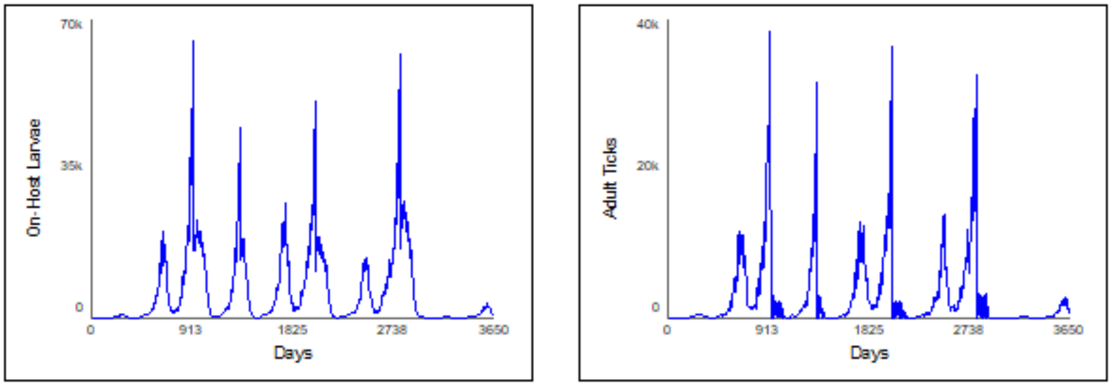
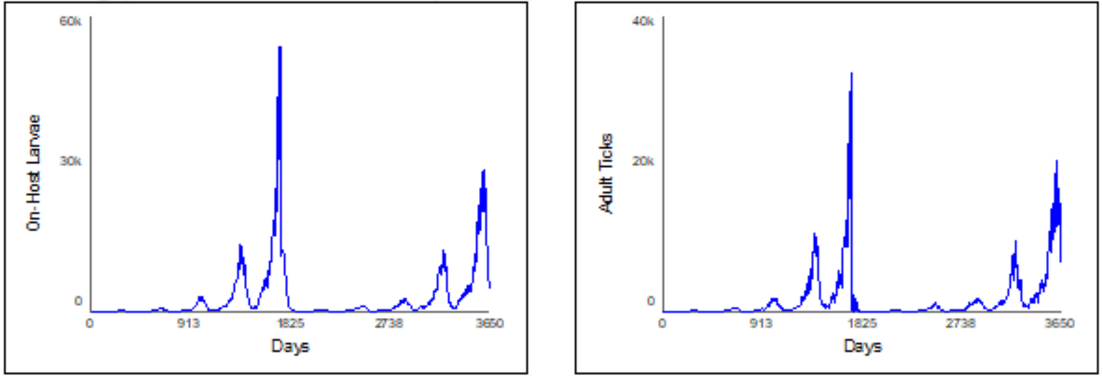
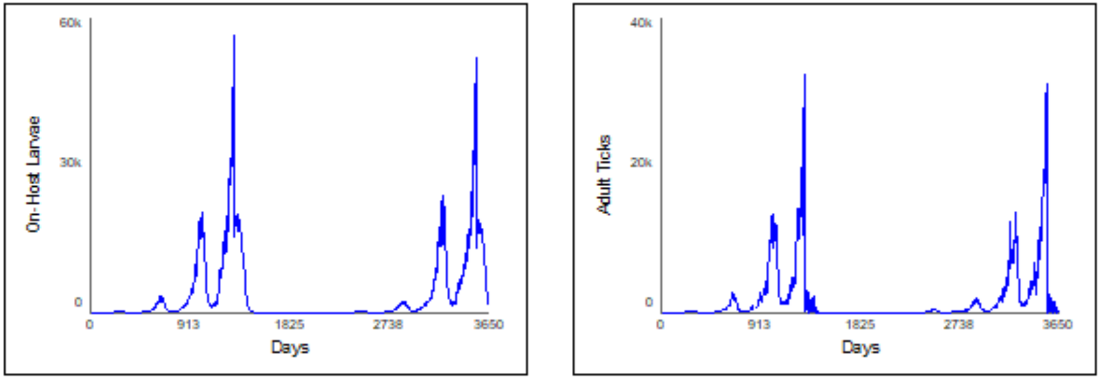


Figure 7. On-host larvae and adult tick population dynamics treated with acaricide dipping

Vacating (Attachment rate = 0.0025)



Vacating (Attachment rate = 0.0025)



Vacating (Attachment rate = 0.003)

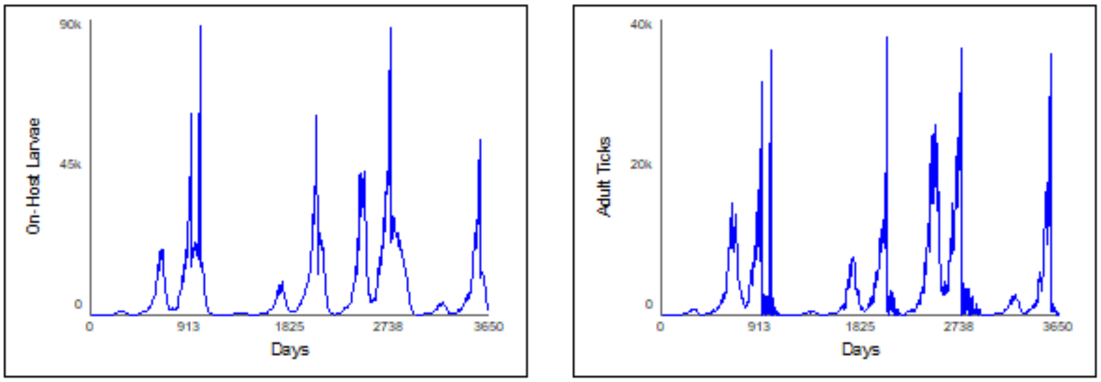


Figure 8. On-host larvae and adult tick population dynamics treated with vacating

Tick populations are highest in every eradication protocol, and when no treatment occurs under higher attachment rates. In addition to an increased quantity of ticks present in the system, populations grow at a faster rate under a higher attachment rate. Tick populations grow to, and are sustained at a higher level when no treatment occurs than any system in which eradication procedures to occur. Under eradication procedures, tick populations may rebound from a near-zero population, requiring an extended or additional quarantine. These near-zero populations could consist of only larvae, or a small number of undetected adults, making their detection less likely and leading to the population rebounds.

Table 6 describes the cost associated with vaccinating, dipping on-site, and dipping or spraying on site at different CFT larvae attachment rates. In all eradication options the least costly CFT attachment rate, on average, was 0.20%, the lowest probability of attachment. The lowest probability of attachment also led to the lowest average number re-infestations in all eradication strategies. In all eradication options the most costly CFT attachment rate, on average, was 0.30%, the highest probability of attachment. The highest probability of attachment also led to the highest average number of individual quarantines in all eradication strategies. Under all attachment rates dipping/spraying on-site was the mean least-cost eradicate strategy. The highest average cost eradication strategy was dipping off-site under all attachment rates.

The lowest number of individual quarantines varied based on attachment rates between dipping off-site and dipping on-site. Under attachment rate 0.25% and attachment rate 0.30% dipping off-site required fewer individual quarantines and under 0.20% attachment rate dipping/spraying on-site was the least costly. While vaccination remains cheaper than dipping off-site and vacating pastures, this research only covers a ten-year period. The perpetuity of boosters required under the BM86 vaccination schedule will inflate costs beyond the period that is documented in this study. The average time from infestation to a clear inspection was shortest for dipping off-premises and dipping or spraying on-premises (119 days and 116 days, respectively, at an attachment rate of 0.20%).

Table 7 describes the cost associated with vacating a pasture infested with CFT at different larvae attachment rates under high and average wildlife density and absent wildlife. Under all wildlife densities the least costly CFT attachment rate, on average, was 0.20%, the lowest probability of attachment. The lowest probability of attachment also led to the lowest average number of individual quarantines in all wildlife densities. In all wildlife densities the most costly CFT attachment rate, on average, was 0.30%, the highest probability of attachment.

Table 6. Summary statistics of 500 iterations of the cost of vaccinating with BM86, dipping on-site, and dipping/spraying on-site at 0.20%, 0.25%, and 0.30% attachment rates

	Vaccinate (BM86)				Dip off-site				Dip/spray on-site			
Attachment Rate 0.20%	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
Ranch costs	$10,672	$17,319	$ -	$ 6,637	$ 38,484	$ 89,456	$ -	$ 15,650	$10,216	$25,483	$ -	$ 4,179
Treatment count	10.89	24.60	0.00	2.58	1.33	3.00	0.00	0.53	1.29	3.00	0.00	0.53
Average time from infestation to clean inspection (days)	133	270	0	51	120	270	0	48	116	270	0	47
Attachment Rate 0.25%	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
Ranch costs	$13,446	$14,715	$12,546	$ 5,893	$ 86,334	$153,279	$27,071	$ 19,218	$23,959	$38,891	$ 7,490	$ 4,807
Treatment count	16.61	19.23	14.76	1.04	2.99	5.00		0.66	3.04	5.00	1.00	0.60
Average time from infestation to clean inspection (days)	325	450	270	55	269	450	90	59	273	450	90	54
Attachment Rate 0.30%	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
Ranch costs	$14,251	$14,949	$13,514	$ 5,772	$120,589	$178,178	$30,056	$ 19,272	$33,180	$49,068	$15,878	$ 5,123
Treatment count	18.28	19.72	16.76	0.79	4.19	6.00	0.64	0.64	4.20	6.00	2.00	0.64
Average time from infestation to clean inspection (days)	461	630	270	69	377	540	90	58	378	540	180	57

Table 7. Summary statistics of 500 iterations of the cost of vacating pastures as an eradicaiton option under high and average wildlife density and no wildlife

	High Wildlife Density (1 Deer/5 Acres)				Average Wildlife Density (1 Deer/10 Acres)				No Wildlife			
Attachment Rate 0.20%	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
Ranch costs	$ 45,649	$ 91,473	$ -	$16,118	$ 30,659	$ 68,778	$ -	$13,472	$29,601	$ 82,321	$ -	$13,291
Quarantine count	2.04	4.00	0.00	0.66	1.36	3.00	0.00	0.56	1.30	3.00	0.00	0.53
Average time from infestation to clean inspection (days)	183.42	360.00	0.00	59.80	122.76	270.00	0.00	50.60	117.00	270.00	0.00	47.84
Attachment Rate 0.25%	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
Ranch costs	$121,152	$186,041	$ 72,924	$19,619	$ 72,629	$127,507	$35,220	$15,542	$68,448	$127,617	$12,174	$16,499
Quarantine count	5.36	7.00	4.00	0.73	3.24	5.00	2.00	0.60	3.02	5.00	1.00	0.64
Average time from infestation to clean inspection (days)	482.40	630.00	360.00	65.86	291.24	450.00	180.00	54.08	271.98	450.00	90.00	57.93
Attachment Rate 0.30%	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.	Mean	Max	Min	Std. Dev.
Ranch costs	$172,959	$250,559	$113,379	$21,737	$100,570	$159,650	$49,365	$18,215	$94,187	$150,063	$42,769	$17,579
Quarantine count	7.67	10.00	6.00	0.84	4.46	6.00	3.00	0.71	4.17	6.00	2.00	0.67
Average time from infestation to clean inspection (days)	690.66	900	540	76.0034	401.76	540	270	64.0023	375.12	540	180	60.55344

The highest probability of attachment also led to the highest average number of individual quarantines in all wildlife densities. Under all attachment rates no wildlife was the mean least-cost option. The highest average cost eradication strategy was high wildlife density under all attachment rates. The lowest number of quarantines under all attachment rates was the situation in which there was no wildlife.

The model does not appear to be sensitive to the introduction of a small number of wildlife. The model shows greater sensitivity to an increase in wildlife density from average to high. The percent change in total average quarantine cost was greater from average wildlife density to high wildlife density than from a system with no wildlife to a system with average wildlife density. The greatest percent change in cost from a system with no wildlife to a system with average wildlife density did not exceed 10.0%, while the smallest percent change in cost from a system with average wildlife density to a system with high wildlife density was greater than 50.0%.

All eradication options were sensitive to the attachment rate, regardless of the presence of wildlife. The average change in cost from an attachment rate of 0.20% to 0.25% over all categories was 139.0%. The average change in cost from an attachment rate of 0.25% to 0.30% was lower than the change in cost from 0.20% to 0.25%, however still large at 40.0%. The greatest change that occurred due to a change in attachment rate was in the vacating strategy under high wildlife density where the change in mean total cost increased 165.0% from attachment rate 0.20% to 0.25%.

Agency costs are calculated by taking the results of Table 5 and multiplying them by the number of treatment count under each eradication strategy. Table 8 contains the average total cost of each quarantine strategy to TAHC and APHIS.

Table 8. Summary statistics of 500 iterations of the cost of eradication procedures to state and federal animal health agencies including adjacent premises quarantines and check premises quarantines (average wildlife density, 0.20% larval attachment rate).

Eradication strategy	Average	Maximum	Minimum	Standard Deviation
Vaccinate	$1,465,918	$2,379,442	$ -	$426,924
Dip (off-premises)	$1,669,960	$2,813,980	$ -	$373,653
Dip/spray (on-premises)	$1,681,194	$2,813,980	$ -	$354,473
Vacate	$2,237,689	$3,527,635	$ -	$467,182

The most expensive eradication strategy to state and federal animal health agencies is the option to vacate pastures. This is likely due to the high number of repeat quarantines required under the vacating option. TAHC and APHIS only use the vaccination in combating *R. annulatus* (Hasel, 2016), so while vaccinating is the immediately obvious least costly option it is not as effective in *R. microplus* outbreaks as in *R. annulatus*. Of the two remaining available strategies dipping off-site and dipping/spraying on-site are similar in their cost, however this could change with the need to construct a temporary or permanent in-ground vat on-site which can cost from $80,000-$100,000.

Conclusions

Cattle Fever Tick (CFT) infestations cause significant financial hardship, with a quarantine decreasing net cash farm income by up to 150.0% (Anderson et al., 2010). Failing to quarantine and eradicate the pest in Texas leading to an outbreak across the historic range would pose an initial cost of $1.2 billion (Anderson et al., 2010). Losses from a widespread Bovine babesiosis outbreak could exceed that figure.

Quarantine procedures are necessary to prevent the spread of the CFT and the associated economic consequences described. This study contributes to the existing literature regarding the CFT by incorporating the biology of a CFT population into a quarantine system model in order to better determine the number of treatment counts/quarantines required under each eradication protocol. Better understanding the number of treatment counts/quarantines required under each eradication protocol provides a better understanding of the total cost of a quarantine.

While the cost of dipping off-premises is the highest in the short-run, the practiced leads to the shortest amount of time under quarantine (Table 6). The shorter time under quarantine from dipping or spraying leads to a lower overall cost and shorter time under quarantine, which means animals can be moved and/or sold, resulting in reopening revenue streams.

In addition to the complication of wildlife confounding eradication results, ticks have been observed possessing levels of acaricide resistance (Perez de leon et al., 2012).

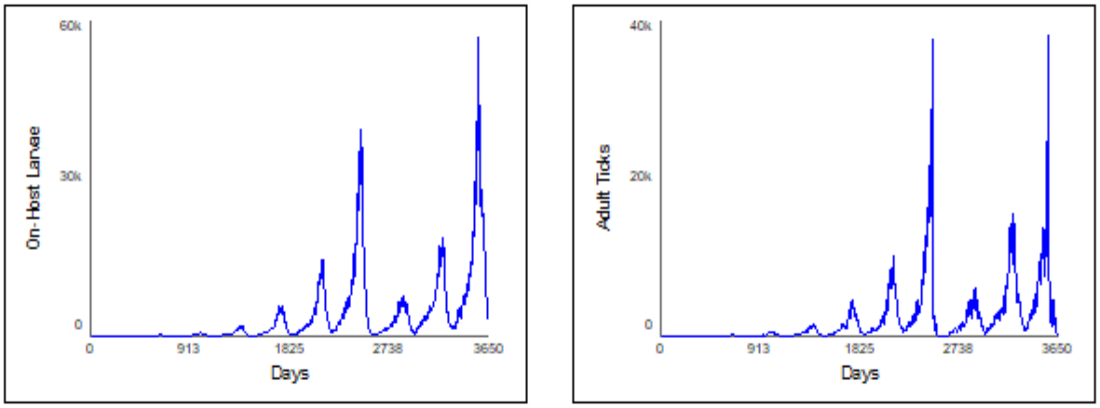


Figure 9. 50.0% acaricide resistant on-host larvae and adult tick population dynamics treated with acaricide with attachment rate 0.002

Figure 9 shows a single model iteration of population dynamics of ticks possessing 50.0% acaricide resistance. Compared to the panels in Figure 7 ticks display an earlier resurgence when they possess acaricide resistance. Not only does the tick population rebound more quickly when ticks possess acaricide resistance, but the rebound results in a higher number of ticks than the scenarios with no acaricide resistance. Acaricide resistant ticks on a single ranch poses significant risk of a longer infestation, and therefore a more costly eradication.

Not all eradication strategies are available to all producers and so the decision will vary based on an individual producer’s circumstances and the technology available (the vaccine is only effective against *R. annulatus*). The model included in this study serves as a template that can be used to evaluate individual outbreaks to estimate the cost of an outbreak to ranchers and government agencies based on the duration of quarantine necessary.

A number of areas for research are available using the model in this study. Further calibration of the wildlife sub-model based on more extensive nilgai data would provide more accurate results, and additional cost data from agency sources would provide a distribution of costs rather than a single figure. In addition to studying the cost of CFT eradication strategies the model in this study can be used as a template for evaluating other invasive pest and disease control methods.

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CHAPTER II

PROFITABILITY OF EAST TEXAS IMPROVED PASTURE STOCKING SYSTEMS

Introduction

“Climate change, whether the result of natural variation or anthropogenic activities, will impact agricultural production throughout the world,” (Mader et al. 2009).

“Adaptation behaviors such as changing crops and crop varieties, adjusting planting and harvest dates, and modifying input use and tillage practices can lessen yield losses from climate change in some regions and potentially increase yields in others where climate change creates expanded opportunities for production,” (Walthall et al. 2013).

There has been much study given to the consequences of climate change on a macro level and to the impacts of climate change on crop production. However, few economic impact studies have estimated direct costs and productivity effects of climate change on livestock, and research on the effects of climate change at a livestock production enterprise level is virtually nonexistent.

The lack of research is due in part to a lack of data spanning enough time to capture the impacts of climate change. The purpose of the following study is to use multiyear pasture stocker grazing experiment datasets provided by F.M.Rouquette, Jr, Texas A&M AgriLife Research at the Texas A&M AgriLife Research & Extension Center at Overton, Texas that spans more than thirty years to estimate the impacts of climate change on cattle stocker operations in east Texas and to provide a framework for future analysis of enterprise level climate change impacts.

The data for this study was provided by F.M.Rouquette, Jr, of Texas A&M AgriLife Research at the Texas A&M AgriLife Research & Extension Center at Overton, Texas and spans more than 30 years. During the study period, faculty and staff at the Texas A&M AgriLife Research & Extension Center recorded birth dates, birth weights, sex, breed, weaning dates, weaning weights, calculated stocking rates, stocking strategies and methods, supplementation strategies, stocking trial begging dates, stocking trial beginning weights, intermediate trial weights, stocking trial terminal weights, average daily gain (ADG) and gain per acre for over 1,800 animals.

Walthall et al. (2013) points out that, “Opportunities for adaptation are shaped by the operating context within which decision making occurs.” The idea that adaptation strategies are approached on a case-by-case basis necessitates the development of micro-level analysis framework of the financial consequences of potential adaptation strategies.

This study uses extensive data describing animal performance and environmental factors to determine the impact of management decisions (adaptations) including supplementation, length of days on pasture (DOP), and stocking rates on profitability in East Texas winter stocker programs.

Review of Literature

Climate Change

“The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC, 2013). The Intergovernmental Panel on Climate Change (IPCC) Summary for Policymakers (SPM) gives a frank summary of one idea: the climate is changing. Economic impacts of climate change are difficult to measure globally with accuracy or locally with relevance, however extensive literature exists attempting to provide general impacts. The following review is only a brief treatment of the substantial body of climate change literature.

Global annual rates of precipitation have changed, decreasing in certain latitudes and increasing in the average overland precipitation for the mid-latitudes of the Northern Hemisphere (IPCC, 2013). In the United States predictions range by area and model, however there is certainty of future change. The Centre National de Recherches Meteorologiques (CNR) general circulation model (GCM), beginning in 1994, forecast dramatic changes ranging from an increase in annual precipitation of up to 173.5 mm in the New England region to a decrease in precipitation of up to 144.9 mm in the southern Great Plains (Malcolm et al., 2012; Déqué et al, 1994). More recent estimates of the Center for Climate System Research MIROC GCM adapted by USDA predict annual precipitation increases of up to 102.7 mm in the Pacific Northwest and a decrease of up to 144.9 mm in the Deep South, and decreases of 3.4 to 38.7 mm in the Pacific Northwest and Southern Great Plains and Texas, respectively (Malcolm et al., 2012). The IPCC's 2013 SPM found that, "The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions."

Temperature change is another effect of the changing climate. “The globally averaged combined land and ocean surface temperature data…show a warming of 0.85 ^{0}C, over the period 1880 to 2012” (IPCC, 2013). Temperature increases have the added impact of increasing evaporation yielding more brackish water in certain regions and lower salinity in others. “In most regions of our country, annual mean temperatures have increased significantly, though considerable variability exists across regions” (Walthall et al., 2013). In addition to regional variability, seasonal variability exists in temperature. The majority of the continental United States has seen increases in temperature ranging from 0.5 ^{0}C to 2.0^{0}C (Walthall et al., 2013) while Alaska has experienced more significant increases ranging from 1.0^{0}C to 2.0^{0}C (Walthall et al., 2013). The Southeastern United States is the only region to experience cooling over the historic period, ranging from a steady temperature to a decrease of between 0.5^{0}C and 1.0^{0}C, although much of the cooling occurred in the mid-20th century with temperatures rising recently (Walthall et al., 2013).

While changes in localized historic temperature are relatively straightforward to measure, forecasts are less certain. The USDA Economic Research Service (ERS) adapted four general circulation models to forecast the change in mean annual maximum temperature under four climate change scenarios and found regional and nation-wide increasing temperatures in all cases. Moderate outcomes from the Max Planck Institute for Meteorology (ECH) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) GCMs found increases ranging from 0.4^{0}C to 2.0^{0}C (Bonan et al., 2002; Roeckner et al., 2003; Malcolm et al., 2012). The previously discussed CNR adapted GCM found more significant increases in temperature ranging from 1.2^{0}C to greater than 3.2^{0}C in the southern Great Plains (Déqué et al, 1994; Malcolm et al., 2012). The most recently developed of the adapted GCMs, the MIROC GCM predicts the most significant changes in temperature with only small portions of the United States seeing mean annual maximum temperature increases of at least 1.6^{0}C and the majority of the continental United States sustaining temperature changes of over 2.8 ^{0}C (Malcolm et al., 2012).

“Carbon dioxide concentrations have increase by 40.0% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions” (IPCC, 2013). Forecasts for cumulative carbon dioxide emissions from 2012 to 2100 vary depending on the Representative Concentration Pathway (RCP), a set of greenhouse gas concentration trajectories in use by the IPCC. All scenarios predict an increase in the emissions of carbon and carbon dioxide from 270 gigatonnes to 1,685 gigatonnes and 990 to 6,180 gigatonnes, respectively (IPCC, 2013).

In addition to gradual, long-term impacts climate change will induce extreme weather and climate events. The IPCC SPM reports more land regions with increasingly heavy precipitation events than locations where such events have decreased. “Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases” (IPCC, 2013). Chen and McCarl (2009) examined the cost of an increase in the frequency and intensity of hurricanes on the agricultural sector, motivated by the billions in property damage exacted by hurricanes Katrina and Andrew, and found that regional crop yields are reduced from 0.20% to 12.9%. A similarly devastating hurricane season occurred in 2017 with hurricanes Harvey and Irma making landfall.

Impact of climate change on plant growth

The changing climate does not impact all plant growth equally. Certain regions will benefit from redistributed precipitation while others will see reduced vitality and some plant species will benefit while others will experience reduced growth.

The body of literature tends to agree that increased CO_2 is beneficial up to a threshold for plant growth. Izaurralde et al. (2011) found that, “In general, it is expected that increases in CO_2 and precipitation will enhance rangeland net primary production (NPP) whereas increased air temperature will either increase or decrease NPP.” C_4 plants (corn, sorghum and bahiagrass) are under CO_2 saturation under ideal precipitation amounts however, C_3 plants (wheat, rye, oats and soybeans) will benefit from increasing concentrations of CO_2 (Izaurralde et al., 2011) and can experience substantial variation in the timing of annual greening and growth (Baker et al., 1993). Doubling of CO_2 can increase yield by up to 30.0% in select C_3 species (Hatfield et al., 2011).

Temperature increase should increase the length of the growing season through earlier green-up in rangeland (Badeck et al., 2004) and temperature is the primary climate driver that will determine growing season length (Izaurralde et al., 2011). Wan et al. (2005) found an increase in above ground NPP of 19.0% from a 2.0^0C increase in daily minimum air temperature of tallgrass prairie, a C_4 species. Controlling for interaction from changing precipitation associated with increased temperature,

temperature increases may enhance productivity however in already hot and dry regions these increases can lead to negative effects on NPP. Water loss associated with warming could offset any direct benefits of increased temperature (Izaurralde et al., 2011).

In non-managed pasture/rangeland, the timing and geographic distribution is the determining factor in soil water availability and its impact on plant growth. Mu et al. (2013) found that as temperature and precipitation increased agricultural commodity producers reduced crop-land and increased pastureland. In general, adequate amounts of precipitation promote sustained growth and when plants receive below a certain threshold, depending on the species, their growth is less than optimal. The quantity of precipitation is not the only important factor in determining growth; timing also plays a role (Izaurralde et al., 2011). In an experiment in a tallgrass prairie ecosystem in Kansas increased variability in precipitation led to a reduction in soil water content and an associated 10.0% decrease in NPP (Knapp et al, 2002; Fay et al., 2003). In addition to forages available on pasture, certain supplements are dependent on precipitation. In a meta-analysis, Izaurralde et al. (2011) found that variation in precipitation will have a greater impact on alfalfa yield in the United States than CO_2 concentrations or variations in temperature. Additionally, decreased precipitation and variability in the timing of precipitation will decrease yields of both soybeans and corn, key components of many supplemental feed mixes (Malcolm et al., 2012).

Direct impacts of climate change on livestock

The indirect effects previously discussed may impair animal production more than direct effects, and more research is needed, however, direct effects from climate change do exist. Studying the direct effects of changing temperature and increased CO_2 concentrations on livestock is difficult due to lack of sufficient data, confounding impacts and the difficulty of experimental integrity year over year, however some general conclusions have been reached. Postulated direct impacts of climate change on livestock include temperature-related illness and death, morbidity during extreme events, decreased voluntary feed intake, and below-optimal reproductive rates (Nardone et al., 2010; Walthall et al., 2013; Zhang et al., 2013).

Voluntary feed intake above the maintenance threshold is the primary factor in determining production value in livestock. Mader et al. (2009) measured the impact of increased average daily temperature due to increased CO_2 concentrations on voluntary feed intake in yearling feeder cattle between 770 lbs. and 1,200 lbs. Under a doubling and tripling of atmospheric CO_2 levels beef producers would need to feed yearling feeder cattle up to 16.0% longer, however increases of four to five percent would be more common, and the magnitude of change was greater for swine than in beef cattle, and greatest for the eastern/southern region of the United States. As a result of decreased voluntary feed intake females are less likely to meet their feed maintenance requirements and therefore lack the nutrition necessary to breed and successfully maintain pregnancy status full-term.

Individual studies have found localized negative responses to heat stress. Cook et al. (2002) and Yeruham et al., (2003) found a higher occurrence of mastitis during periods of hot weather. During a period of high heat stress in Italy in 2003 cell-mediated immunity in high yielding dairy cows was significantly impaired (Lacetera et al., 2005).

Nardone et al., 1997 suggested that heat stress may impair the protective value of colostrum in cows, and the negative influence of heat stress on beneficial colostral effects may explain the higher mortality of newborn calves observed during hot months (Martin et al., 1975). During summer, ketosis has is more prevalent due to increased maintenance requirements for thermoregulation and lower feed intake (Lacetera et al., 2005), and the incidence of lameness increases as a consequence of metabolic acidosis (Shearer, 1999). In addition to the fore-mentioned studies, numerous experiments have documented detrimental impacts of high heat load, the interaction of radiation, temperature humidity and wind speed (Johnson, 1987), on feed intake and efficiency, yield, animal health, growth and egg and milk production (Hansen et al., 2001; Wolfenson et al., 2001; Yalchin et al., 2001; Valtorta et al, 2002; Kerr et al., 2003; Faurie et al., 2004; Gaughan et al., 2004, Holt et al., 2004; Gaughan et al., 2009; Renaudeau et al., 2011).

Studies on the correlation between heat stress and immune responses may be contradictory to each other with some reporting improvements and some impairments. The wide-ranging variety of experimental conditions (breed, species, location etc.) and lack of exact replication in repeated studies are likely to explain these discrepancies (Gaughan et al., 2009).

Stocker cattle systems

Peel (2006) describes the role of the stocker industry as providing a high degree of flexibility for the cattle industry, adjusting the timing and level of beef production according to market signals. The flexibility the stocking system provides is due to the variability present between different operations, which makes the sector difficult to generalize, however certain attributes are constant throughout.

Peel (2006) describes typical stocker systems using data from USDA, 1995-2005. Table 9 summarizes Peel's findings regarding the typical stocker enterprise and table represents various combinations of typical stocker animals over a variety of production systems.

Table 9. Stocker production characteristics.

Stocker production characteristic	Typical	Range
Beginning weight (lb.)	400-500	300-650
Rate of gain (lb./d)	1.5-2.5	1.0-3.5
Total gain (lb.)	200-300	100-400
Ending weight (lb.)	650-850	600-950
Length of time (days)	100-200	75-300

The characteristics of an individual stocker system are dependent upon available forage, which dictates cattle, duration of grazing, and feeding program (Huston et al., 2011). Asem-Hiablie et al. (2015, 2016, 2017, 2018) collected and described region-specific cattle production information. Asem-Hiable et al. (2018) describes management characteristics of eastern U.S. cattle producers. Of stocker operations surveyed in the Southeast (n=659), the mean number of head was 176 and the mean stocking rate was 1.48 acres/stocker calf (Asem-Hiablie et al., 2018). Of the farms surveyed, the average amount of concentrate fed as a supplement was about 1.32 lb. of dry matter per day (DM/d), per animal. Purebred Angus and predominately Angus crosses were reported on 70.0% of the operations surveyed (Asem-Hiablie et al., 2018).

Grazing stocker cattle systems exist on rangeland and pastureland in Texas. Huston et al. (2011) reported that in the lower rainfall areas of Texas, generally the western region, rangeland grazing is the dominant system. Larger pastures undisturbed by mechanical means, usually with native vegetation unenhanced except for grazing are characteristic of rangeland. Pastureland grazing, the system used at the Texas A&M AgriLife Research & Extension Center at Overton, Texas occurs in areas of higher rainfall in the eastern part of Texas. Pastureland grazing systems typically involve more management than rangeland systems through cultivation, fertilization, irrigation or another non-grazing enhancement (Huston et al., 2011).

Grasses such as bermudagrass (*Cynodon dactylon L.*) and bahiagrass (*Paspalum notatum* Flueggé), and legumes including alfalfa (*Medicago sativa* L.) and clovers dominate warm-season pastureland stocker systems in the Southeast (Asem-Hiablie et al., 2018). Annual ryegrass (*Lolium* spp.), winter cereal rye (*Secale cereal* L.), and winter wheat (*Triticum aestivum* L.) were used in the Southeast during winter months to extend the grazing season (Asem-Hiablie et al., 2018). Warm-season perennial forage mass is characterized by a bimodal distribution where peak production occurs from late April through late summer with a secondary increase in mid-fall (Duble et al., 1971; Guerrero et al., 1984; Rouquette, 2015). Cool-season annual forage growth is characterized by a bimodal distribution that is temperature-driven, resulting in a minor peak in the fall and significant forage production in the late winter and spring

Bermudagrass is the most persistent warm-season perennial grass used in pastureland grazing in the southeastern U.S. (Rouquette, 2016) and is the warm-season perennial grass of choice for the Texas A&M AgriLife Research & Extension Center at Overton, Texas. The release of Coastal bermudagrass (*Cynodon dactylon* (L.) Pers) in the mid-1940s dramatically increasing production per acre (Rouquette and Smith, 2010). Sollenberger and Vanzant (2011) found that forage mass and forage allowance sets the parameters for potential ADG while nutritive value is responsible for setting the upper limits of potential ADG in bermudagrass pastures.

Managed pastureland cool-season stocker systems typically follow one of two courses; sod-seeding (overseeding) of cool-season annual grasses and legumes onto warm-season perennial forages, or introduction of small grains into prepared seedbed via drilling or sod openers (Rouquette, 2015; Rouquette, 2016; Asem-Hiablie et al., 2018). Winter wheat varieties have long been used on prepared seedbed in parts of western Texas, Oklahoma, and Kansas in a mixed system of grain production and stocker grazing (Rouquette, 2015).

Similar to the rest of the southeastern U.S. the Texas A&M AgriLife Research & Extension Center at Overton, Texas overseeds bermudagrass with cool-season annual forage or legumes. “Cool-season annual clovers and legumes are used in combination with perennial grasses such as bermudagrass to extend the active grazing period and provide increased nutritive value” (Rouquette, 2016). Early examples of sod-seeding oats or ryegrass in warm-season perennial grasses began as early as the 1940s (Dudley and Wise, 1953), and numerous studies have evaluated techniques and seeding rates for small grains, ryegrass or clovers into bermudagrass and other perennial grasses (Stephens and Marchant, 1958; Swain et al., 1965; Welch et al., 1967; Matocha, 1975). Overseeding of clovers and other legumes introduce benefits from nitrogen fixation through their symbiotic nitrogen (N) fixation and spring weed control (West and

Mallarino, 1996; Rouquette and Smith, 2010). Beck et al. (2007), Rouquette and Smith (2010), and Beck et al. (2013) examined an array of stocking strategies for stocker cattle using bermudagrass overseeded with small grains and ryegrass and determined that an initially low stocking rate accompanied by a doubling of the stocking rate in March maintains a stocker ADG of 1.25 kg d^{-1}.

Another consideration when grazing stocker calves is whether or not to provide an energy or protein supplement. The decision is influenced heavily by individual circumstance but follows basic principles across stocking systems attempting to maximize profit. There are several reasons for supplementing stocker cattle including improving ADG, allowing for increased stocking density when forage is adequate or accounting for a lack of nutrients when forage is limited, and supplying additives (Cravey, 1993, Huston et al., 2011). In the southeastern U.S. farmers purchased 0.59 kg of concentrate dry matter (DM)/animal per day (Asem-Hiablie et al., 2018) for supplemental feeding.

Huston et al. (2011) describes four supplemental feeding strategies: 1) Supplemental feeding involves providing limiting nutrients to allow forage to reach the potential level such that animal performance is not restricted by the deficiencies of other nutrients; 2) Enhancement feeding is utilized to increase the rate of gain or feed efficiency; 3) Substitution feeding requires alternate feeds be used to reduce or substitute the intake of grazed forage; 4) Supply feeding provides a major or exclusive portion of the animals' DM in the event of inadequate forage quantity.

Considering the highly digestible nutrients of cool-season annual forages offering supplemental concentrates has two primary objects: 1) to use cheap grain sources to add animal weight economically and 2) to buffer the effect of over-stocking pastures to extend long-term pasture health (Grigsby et al., 1988c; Lippke et al., 2000; Pinchack et al., 1989; Huston et al., 2011).

Table 10. Effects of concentrates on growing cattle grazing Coastal bermudagrass pasture

	Treatments										
Items	**Pasture**	**Corn**	**Condensed molasses block**	**Cottonsead meal**	**Soybean meal**	**High fish meal concentrate**	**High feathermeal concentrate**	**Corn and Rumensin**	**Cottonseed meal and Rumensin**	**Low solubility fish meal**	**Feather meal and Rumensin**
Suppl. Intake, lb/d											
Hutcheson et al. (1986)								3.12	1.37	1.28	
Grigsby et al. (1989)			0.44	1.92		0.46				1.12	
Grigsby et al. (1989)			0.50		1.05	1.60				0.84	
Rouquette et al. (1993)						1.25	1.25				
Lippke and Ellis (1991)		0.91				0.74					
Ellis et al. (1995)				1.89					1.89		1.57
Average daily gain, lb/d											
Hutcheson et al. (1986)	1.50							1.84	1.88	2.14	
Grigsby et al. (1989)	1.04		1.29	1.52		1.21				1.92	
Grigsby et al. (1989)	0.84		1.10		1.54	1.37				1.49	
Rouquette et al. (1993)	1.17									1.57	1.82
Lippke and Ellis (1991)	0.60	1.00				1.02					
Ellis et al. (1995)	1.08			1.36					1.64		1.64
Supplement/incremental gain, lb											
Hutcheson et al. (1986)								9.20	3.60	2.10	
Grigsby et al. (1989)			1.80	4.00		2.70				1.30	
Grigsby et al. (1989)			1.90		1.50	3.00				1.30	
Rouquette et al. (1993)						3.20	2.00				
Lippke and Ellis (1991)		2.20				1.70					
Ellis et al. (1995)				6.80					3.40		2.80

Source: Huston et al. (2011)

Huston et al. (2011) provided an excellent overview of feeding different concentrates on stocker cattle grazing Coastal bermudagrass pasture. Table 10 is an adaptation of their summary table describing supplemental intake (lb./d), average daily gain (lb./d), and incremental gain (lb.) from supplement feeding over six grazing experiments. Average incremental gain across all six studies was 3.06 lb. The data from trials at the Texas A&M AgriLife Research & Extension Center at Overton, Texas includes mixes of corn, feather meal, molasses, soybean meal, Rumensin®, Bovatech®, GainPro®, amino acids, fishmeal, and gluten fed as concentrate supplement.

Adaptation strategies for climate change in the livestock sector

The climate is changing and certain impacts are irreversible. The new state of the climate means that production practices must change in certain circumstances in order to achieve optimal profit, and in some cases the optimal profit has been irreversibly changed; these changes and new practices are strategies of adaptation. Gaughan et al. (2009) summarizes adaptation strategies by the livestock industry and established five categories for adaptation:

1. Variations among breeds, species, and genotypes of both animal and forages
2. Adjustment of livestock feed ration
3. Management of livestock grazing intensities
4. Alteration of facilities including barn construction and misters
5. Relocation of livestock among regions

In the case of acute heat stress animal survival will be managed more cost-effectively through environmental alteration per item four in the previous list (shade, misters, etc.), however in chronic heat-stress the effect of thermal stress cannot be eliminated by environmental modification and even major gains would be cost-prohibitive (Renaudea et al., 2011). Genetic selection may hold the key to improving heat load tolerance in livestock experiencing chronic heat-stress. The "slick coat" gene which yields cattle with shorter hair has been observed to be more heat tolerant and present in tropical *Bos taurus* breeds (Gaughan et al., 2009). Zhang, Hagerman, and McCarl (2013) have found that producers in areas where heat stress is common select for more heat-tolerant cattle such as *Bos indicus* (Brahman). Producers have also transitioned to crosses of the English *Bos taurus* breeds with *Bos Indicus*, which has shown to be more hearty in the face of high heat-stress and pest resistance.

There is evidence that in certain circumstances genetic adaptation within a species is not sufficient to provide economic returns above investment cost, and in some of these cases producers are turning to new species entirely. Seo, McCarl and Mendelsohn (2010) found shifts in species from cattle to sheep and goats in South America after controlling for soils, geography, household characteristics, and country fixed effects. "Sheep and goats are thought to be less susceptible to environmental stress than other domesticated ruminants" (Khalifa et al., 2005). The difference in species' ability to withstand heat stress and lack of water should allow for selection of appropriate species for production practices, however markets for these species products could serve as a limiting factor for their adoption (Joyce et al., 2013).

Adjusting stocking rates and varying the method of grazing by season and species of grass has proven to be another effective tool in adapting to climate change in livestock production. O'Reagain et al. (2011) found that financial returns were maximized after 12 years of adjusting stocking rate based on available forage followed by a moderate set-stocking rate. Using production characteristics of New Mexico, Torell et al., (2010) found that forage dependent stocking strategies as viable options to adapt to drought by allocating a significant part of a cow-calf enterprise to a flexible yearling enterprise. In a description of drought management in rangeland cattle grazing, Hart and Carpenter (2005) recommend that no more than 50.0% to 70.0% of grazing carrying capacity be allocated to a cow herd, and the remainder should be left as flexible grazing for drought management in times of inadequate precipitation and available for a stocker enterprise in periods of adequate precipitation.

Extensive options for environmental modification exist, depending on the individual practice, and are described by Gaughan et al. (2009) as including, but not limited to:

1. Shade
2. Air movement
3. Using water for cooling livestock
4. Direct water application

Each of these options has seen varying ranges of success and is highly dependent upon the resources available to producers, the species and breed in question, and the cost-benefit of each option (Renaudeau et al., 2011; Gaughan et al., 2009).

There is an extensive body of literature surrounding the operation of stocker enterprises and even more for climate change. This research will contribute to the body of literature for the impact of changing temperature and precipitation on livestock production, and the profitability of those enterprises. In addition, this research will provide a template for studying the impact of other micro-climate changes on livestock enterprise profitability.

Data & Methodology

Data

The data for this study was provided by F.M.Rouquette, Jr, of Texas A&M AgriLife Research at the Texas A&M AgriLife Research & Extension Center at Overton, Texas and spans more than 30 years. During the study period, faculty and staff with Texas A&M AgriLife Research recorded birth dates, birth weights, sex, breed, weaning dates, weaning weights, calculated stocking rates, stocking strategies and methods, grazing methods, supplementation strategies, stocking trial beginning dates, stocking trial beginning weights, intermediate trial weights, stocking trial terminal weights, average daily gain (ADG) and gain per acre for over 1,800 animals.

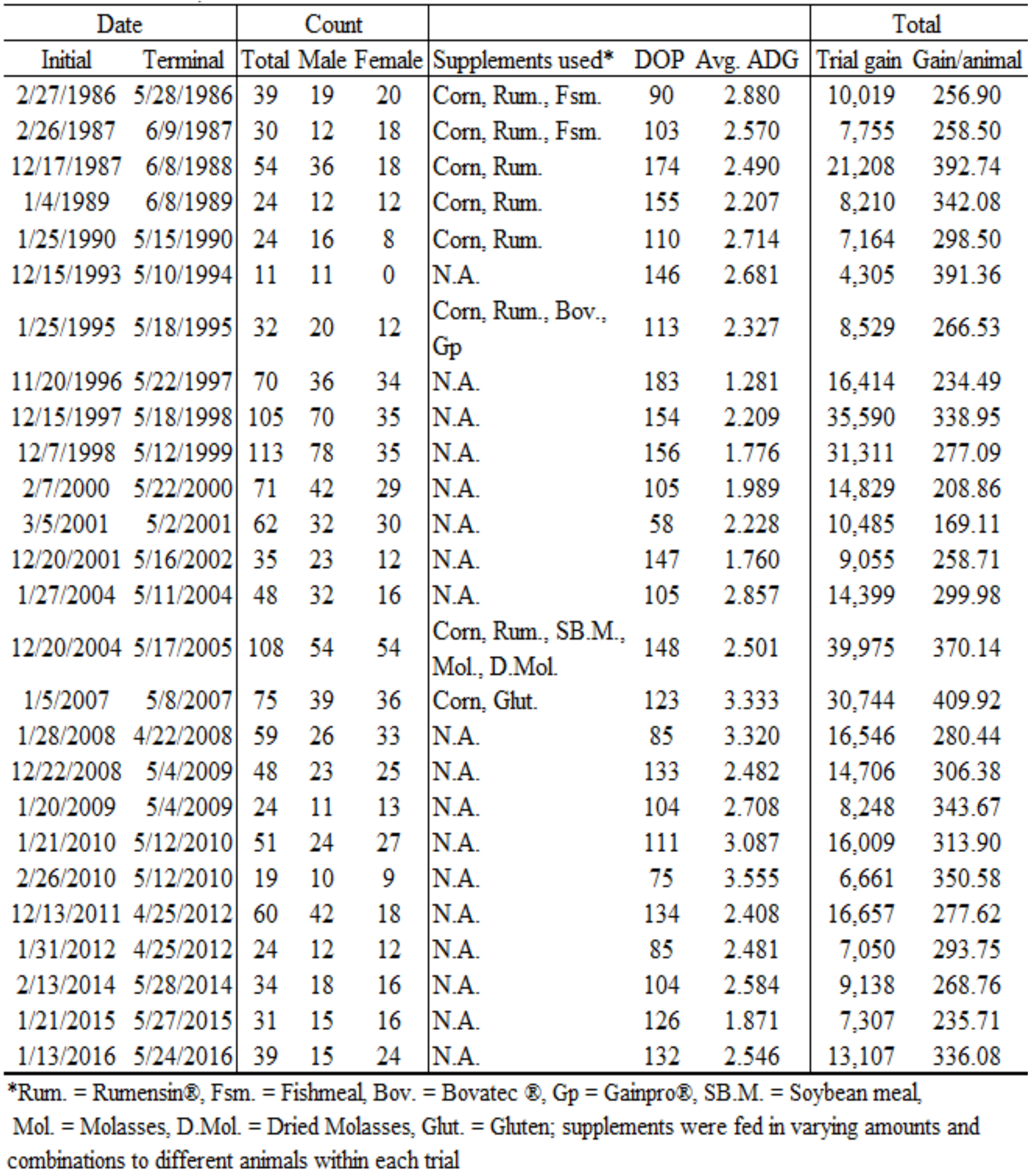
Table 11 is a summary of the breeds of animals included in the rye and ryegrass grazing experiments. Each animal was counted based on the attribute of sire. All of the dams for the stockers in the stocking trials were F-1 (Brahman x Hereford or Brahman x Angus)

Table 11. Summary of breeds by breed of sire of cattle in stocking trials at Texas A&M AgriLife Research & Extension Center at Overton, TX.

	Breed			
	Hereford	Angus	Simmental	Tropically-adapted sires
Count of animals over time	5	246	983	48

Table 12 is a summary of the trials that were included in this study. Of the original set provided by F.M.Rouquette, Jr., 514 observations were eliminated for lack of information regarding sex, birthweights, weaning weights, trial beginning and ending weights, breed information, or if there was an associated note regarding unusual circumstances.

Table 12. Summary of stocking trials at Texas A&M AgriLife Research & Extension Center at Overton, TX



Date		Count						Total	
Initial	Terminal	Total	Male	Female	Supplements used*	DOP	Avg. ADG	Trial gain	Gain/animal
2/27/1986	5/28/1986	39	19	20	Corn, Rum., Fsm.	90	2.880	10,019	256.90
2/26/1987	6/9/1987	30	12	18	Corn, Rum., Fsm.	103	2.570	7,755	258.50
12/17/1987	6/8/1988	54	36	18	Corn, Rum.	174	2.490	21,208	392.74
1/4/1989	6/8/1989	24	12	12	Corn, Rum.	155	2.207	8,210	342.08
1/25/1990	5/15/1990	24	16	8	Corn, Rum.	110	2.714	7,164	298.50
12/15/1993	5/10/1994	11	11	0	N.A.	146	2.681	4,305	391.36
1/25/1995	5/18/1995	32	20	12	Corn, Rum., Bov., Gp	113	2.327	8,529	266.53
11/20/1996	5/22/1997	70	36	34	N.A.	183	1.281	16,414	234.49
12/15/1997	5/18/1998	105	70	35	N.A.	154	2.209	35,590	338.95
12/7/1998	5/12/1999	113	78	35	N.A.	156	1.776	31,311	277.09
2/7/2000	5/22/2000	71	42	29	N.A.	105	1.989	14,829	208.86
3/5/2001	5/2/2001	62	32	30	N.A.	58	2.228	10,485	169.11
12/20/2001	5/16/2002	35	23	12	N.A.	147	1.760	9,055	258.71
1/27/2004	5/11/2004	48	32	16	N.A.	105	2.857	14,399	299.98
12/20/2004	5/17/2005	108	54	54	Corn, Rum., SB.M., Mol., D.Mol.	148	2.501	39,975	370.14
1/5/2007	5/8/2007	75	39	36	Corn, Glut.	123	3.333	30,744	409.92
1/28/2008	4/22/2008	59	26	33	N.A.	85	3.320	16,546	280.44
12/22/2008	5/4/2009	48	23	25	N.A.	133	2.482	14,706	306.38
1/20/2009	5/4/2009	24	11	13	N.A.	104	2.708	8,248	343.67
1/21/2010	5/12/2010	51	24	27	N.A.	111	3.087	16,009	313.90
2/26/2010	5/12/2010	19	10	9	N.A.	75	3.555	6,661	350.58
12/13/2011	4/25/2012	60	42	18	N.A.	134	2.408	16,657	277.62
1/31/2012	4/25/2012	24	12	12	N.A.	85	2.481	7,050	293.75
2/13/2014	5/28/2014	34	18	16	N.A.	104	2.584	9,138	268.76
1/21/2015	5/27/2015	31	15	16	N.A.	126	1.871	7,307	235.71
1/13/2016	5/24/2016	39	15	24	N.A.	132	2.546	13,107	336.08

*Rum. = Rumensin®, Fsm. = Fishmeal, Bov. = Bovatec ®, Gp = Gainpro®, SB.M. = Soybean meal, Mol. = Molasses, D.Mol. = Dried Molasses, Glut. = Gluten; supplements were fed in varying amounts and combinations to different animals within each trial

Additional trials were conducted, however they were excluded for the aforementioned missing data. Table 13 summarizes the growth and attributes of the animals included in the study.

Table 13. Summary of animals included in the winter pasture study

	Birth weight (lbs.)	Female	Wean weight	Prewean ADG (lbs.)	Weaning age (days)
Mean	85	0.45	598	2.22	233
Std. Dev.	15	0.5	71	0.31	20
Min	42	0	375	-0.12	153
Median	84	0	598	2.21	236
Max	152	1	876	3.76	289

	Pretrial ADG (lbs.)	Age at stocking (days)	Initial stocking weight (lbs.)	Stocking rate	Days on pasture
Mean	1.89	335	628	2.62	127
Std. Dev.	0.28	39	78	0.74	30
Min	1.19	110	366	1.04	58
Median	1.88	335	627	2.56	126
Max	5.56	492	908	5.76	183

	Terminal weight (lbs.)	Trial ADG (lbs.)	Total trial gain (lbs.)
Mean	925	2.4	297
Std. Dev.	123	0.85	108
Min	543	-0.40	-23
Median	922	2.49	291
Max	1325	5.12	584

The difference between pre-wean total growth and initial stocking weight represents a pre-stocking period after the calves are weaned. The mean female value (0.45) represents a 45.0% female composition of the stockers over the study period. In order to incorporate the climatic changes on cool-season stocking systems the study includes weather data corresponding to the study period.

For the animals included in the study there was a clear increase in total gain as days on pasture (DOP) increased (Figure 11). During the trial with the least DOP (58), a year with non-normal climate, only two animals achieved 200 lbs. or more of gained weight, while the average total trial weight gained over the average DOP of 127.15 days was 297.34 lbs.

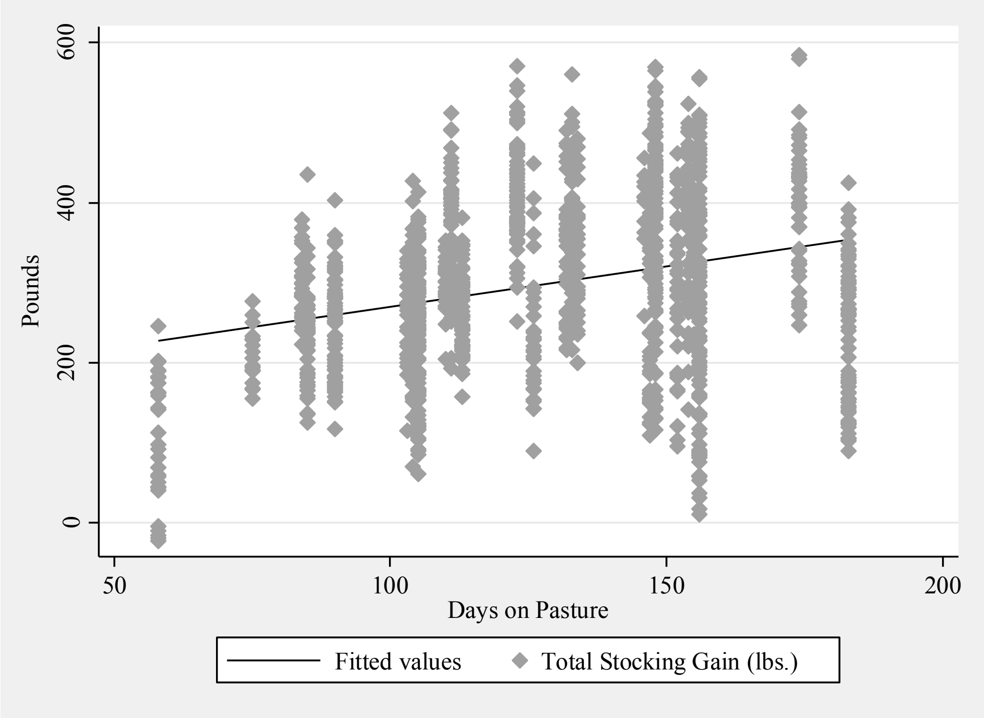


Figure 11. Total stocker gain 1985-2015 (Trend line; Total stocker gain = 169.06 + 1.009*(**Days on pasture**[4]) + ε).

During the study period DOP decreased (Figure 12). Average DOP during the period from 1985-2000 was 139 days while the average number of DOP during the period from 2000-2015 was 119 days, a difference of 20 days, or just over two weeks.

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[4] Bolded variable names represent significance at the 10.0% level.

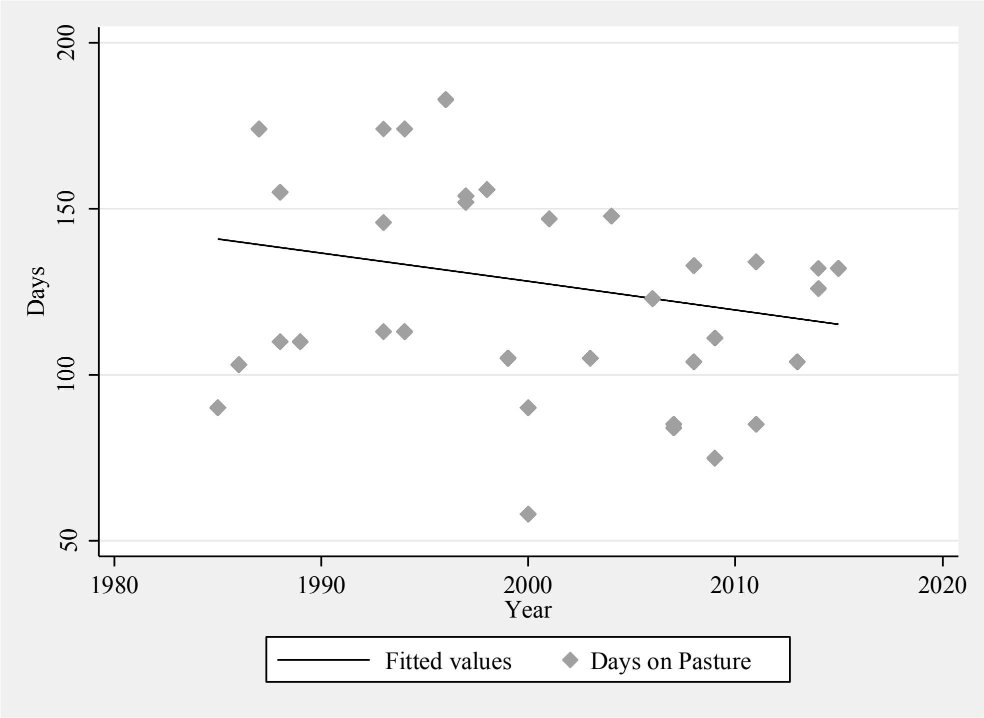

Figure 12. Days on pasture (DOP) 1985-2015 (Trend line; Days on Pasture = 1857.518 - 0.8647***Year**) + ε).

During the same period, temperature and precipitation displayed changes over time. Cool-season annual forage growth is characterized by a bimodal distribution that is temperature-driven, resulting in a minor peak in the fall and significant forage production in the late winter and spring (Rouquette, 2015). Changes to temperature can result in sub-optimal growth, and changes to the timing of a decrease in temperature could result in managers or producers planting at a later date, resulting in fewer DOP.

In order to determine the relationship between temperature and precipitation changes and DOP this study incorporates NOAA monthly precipitation and monthly average maximum and monthly average minimum temperature data from weather stations at Henderson, TX, 15 miles from the Texas A&M AgriLife Research &

Extension Center at Overton, TX, and weather data from the Texas A&M AgriLife Research & Extension Center.

Figure 13 contains the monthly average maximum temperatures for 1985-2015. Monthly average maximum temperatures increased during the study period in all months August-February except for November, which experienced a slight decrease. The most significant increase in monthly average maximum temperature during the study period occurred in the month of October.

Figure 14 contains the monthly average minimum temperatures 1985-2015. Monthly average minimum temperatures over the study period did not vary in the same manner as monthly average maximum temperatures. In November, January, and February monthly average minimum temperatures decreased over the study period. Monthly average minimum temperatures in August, September, and December each experienced slight increases and October's monthly average minimum temperature remained relatively stable over the study period.

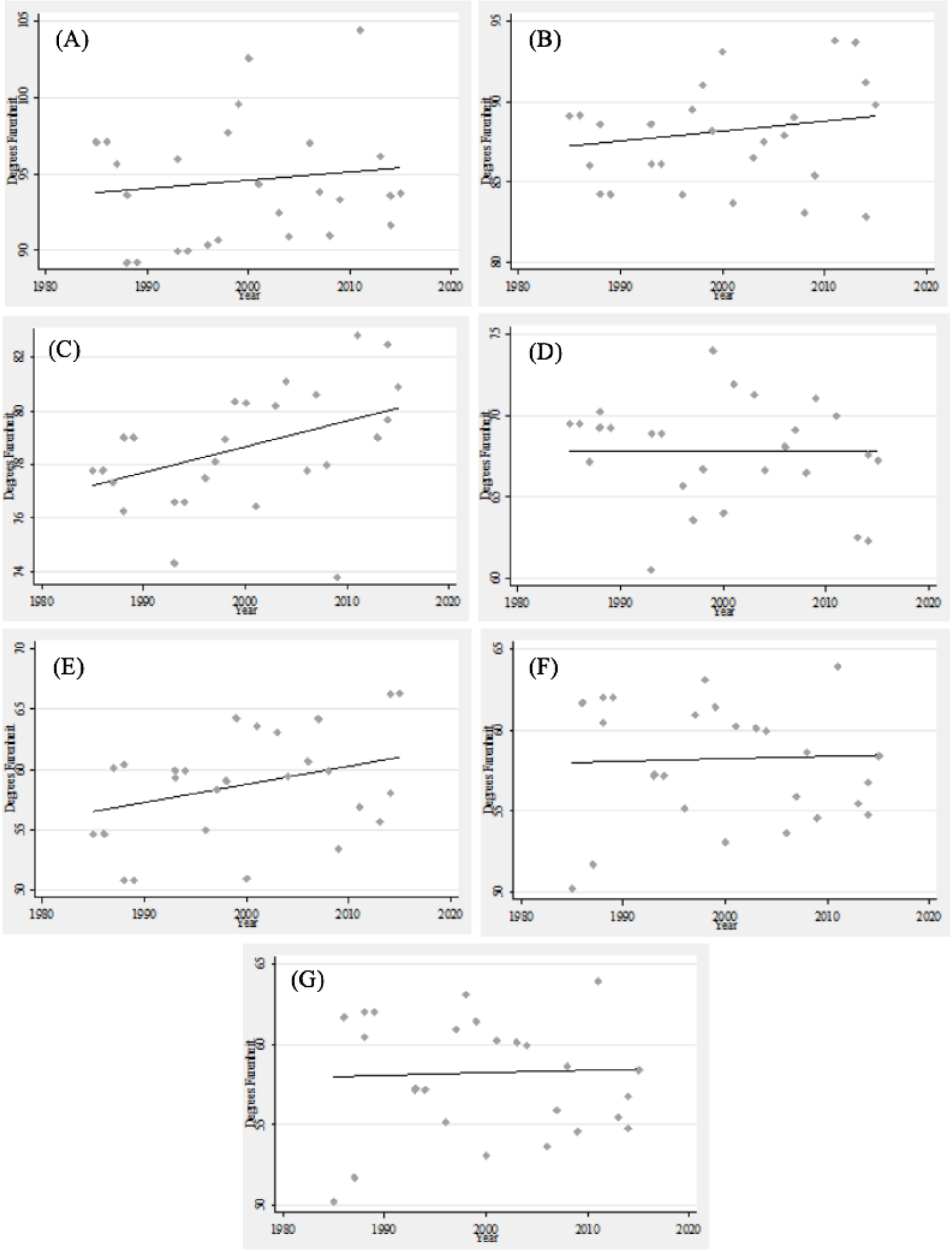

Figure 13. Monthly average maximum temperatures August – Febraury (1985-2015); (A) Aug. Avg. Max Temp. = -13.80 + 0.054*(**Year**) + ε; (B) Sep. Avg. Max Temp. = -35.35 + 0.062*(**Year**) + ε; (C) Oct. Avg. Max Temp. = -114.64 + 0.097*(**Year**) + ε; (D) Nov. Avg. Max Temp. = 70.36 -0.001*(Year) + ε; (E) Dec. Avg. Max Temp = -242.74 + 0.151*(**Year**) + ε; (F) Jan. Avg. Max Temp. = 28.19 + 0.015*(Year) + ε; (G) Feb. Avg. Max Temp. = -334.01 + 0.196*(**Year**) + ε

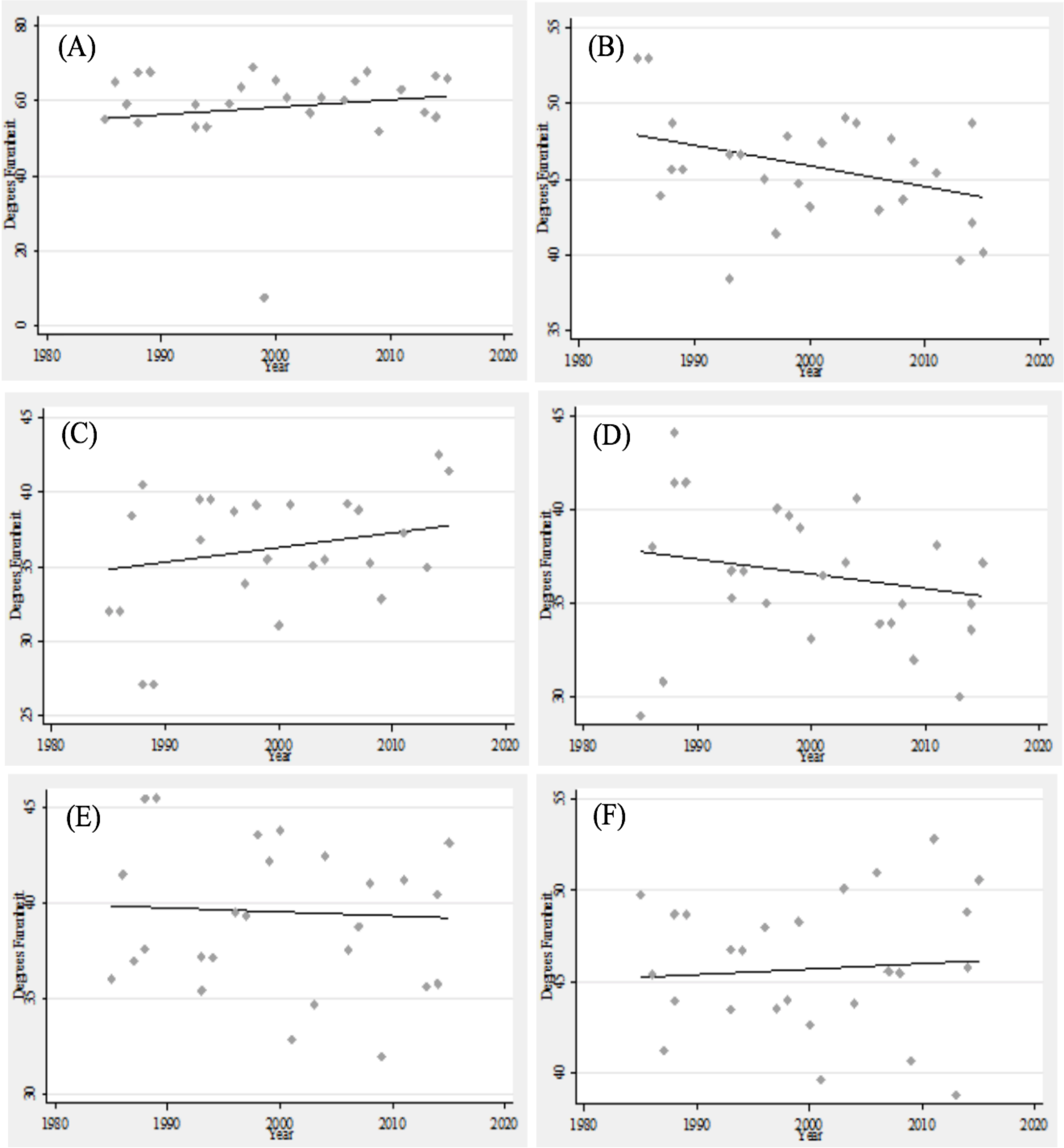

Figure 14. Monthly average minimum temperatures August and November – March (1985-2015); (A) Aug. Avg. Min Temp. = -54.98 + 0.063*(**Year**) + ε; (B) Nov. Avg. Min Temp. = 319.69 - 0.137*(**Year**) + ε; (C) Dec. Avg. Min Temp. = -161.52 + 0.099*(**Year**) + ε; (D) Jan. Avg. Min Temp. = 194.23 -0.079*(**Year**) + ε; (E) Feb. Avg. Min Temp. = 80.5 -0.02*(Year) + ε; (F) Mar. Avg. Min Temp. = -13.36 + 0.03*(**Year**) + ε

There were also changes in precipitation in the area of the Texas A&M AgriLife Research & Extension Center at Overton during the study period. A downward trend exists in total rainfall during the period of September through December, from 1985-2015 (Figure 15).

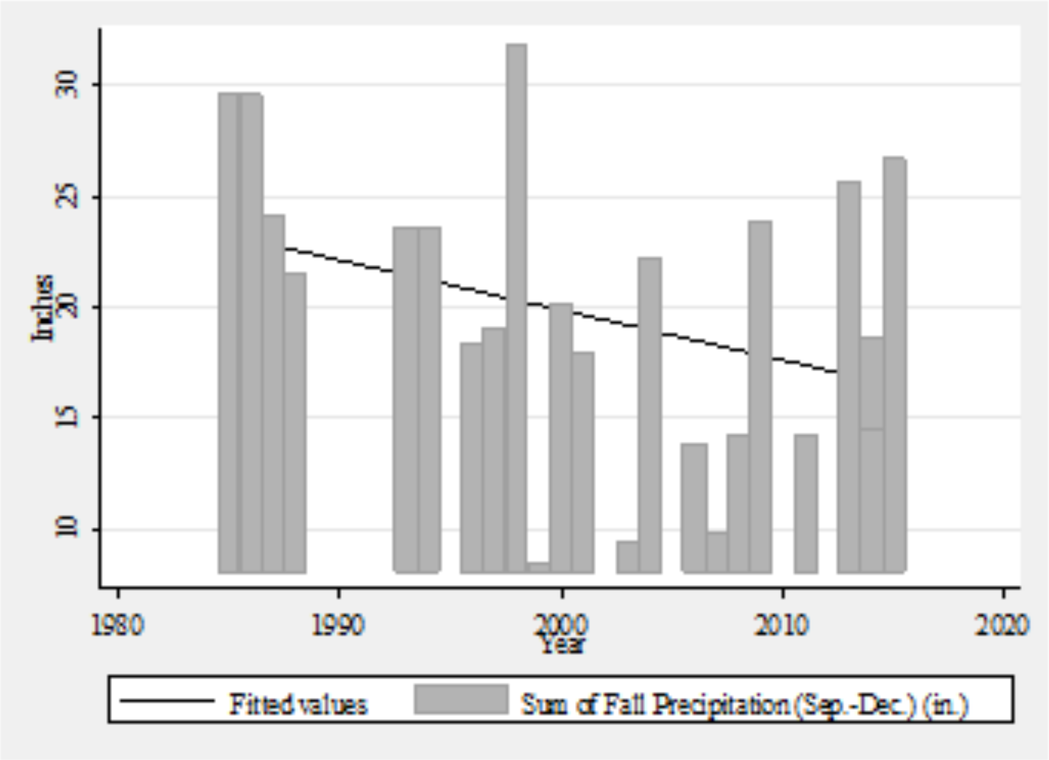

Figure 15. Sum of precipitation September – December (1985-2015)
(Trend Line; Fall precipitation = 469.23 - 0.225*(**Year**) + ε)

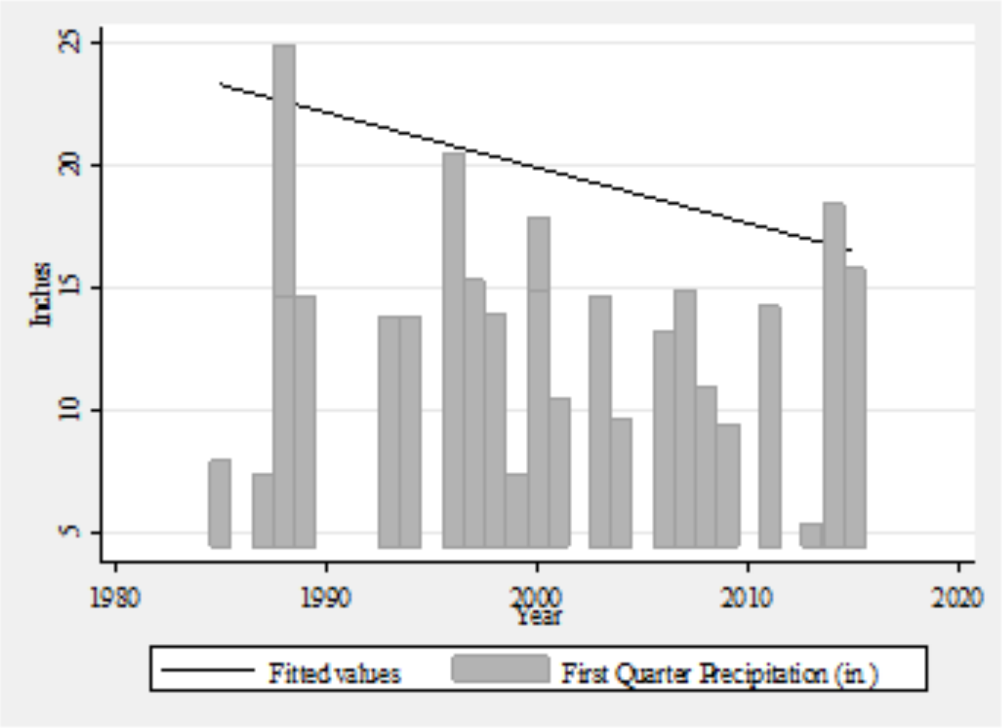

Figure 16. Sum of first quarter precipitation (1985-2015)
(Trend line; First quarter precipitation = 81.49 - .034*(**Year**) + ε)

Total first quarter precipitation decreased over the study period (Figure 16), although not at the same rate as fall precipitation. Precipitation during the period described by Figure 15 occurs during the initial peak growth period of cool-season annual forages (Figure 11) and the secondary peak of warm-season perennial forages.

All else equal, during the study period increased DOP increased total gain per animal; thus fewer DOP would decrease total gain per animal, however changes in birth weight and growth may have offset the decrease in DOP.

Considering Figure 11 and Figure 12 in combination leads to the conclusion that total trial weight gains over time should have decreased. During the study period, fewer DOP is associated with a lower total trial gain and from 1985-2015 the DOP decreased, however from 1985-2015 the total trial gain/animal displays an increasing trend (Figure 17). Total trial gain/animal increased despite decreased DOP from 1985-2015 suggests an increased ADG. Figure 18 illustrates the trend of ADG from 1985-2015. ADG increased from 1985-2015.

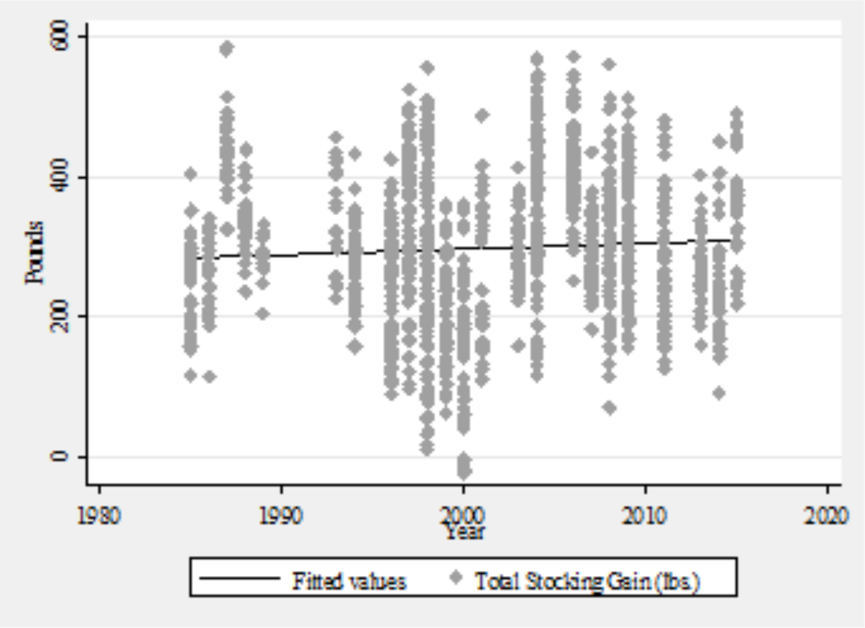

Figure 17. Total stocker gain (1985-2015).
(Trend line; Total stocker gain = -1446.53 + 0.871*(**Year**) + ε)

During the first half of the study period average ADG was 2.095 lbs. /day, while during the second half of the study period average ADG was 2.666 lbs. /day.

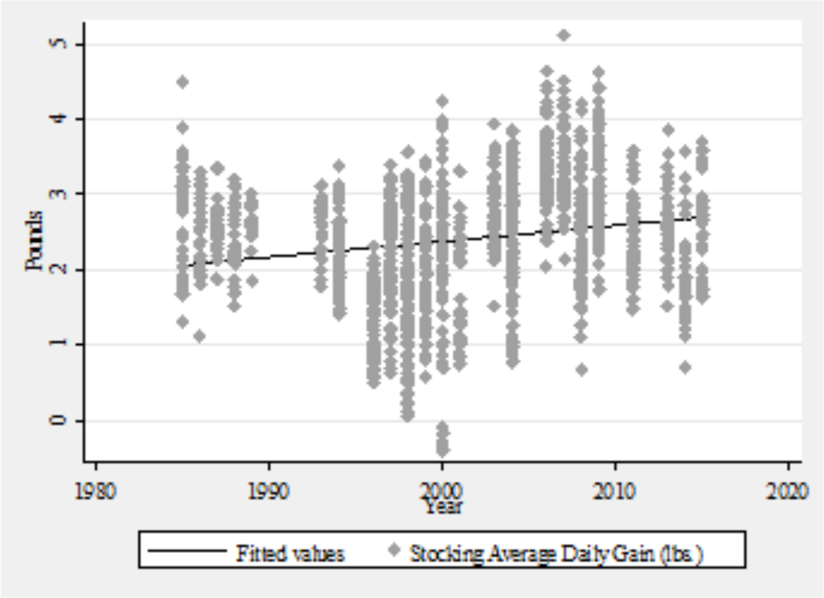

Figure 18. Stocker average daily gain (ADG) (1985-2015).
(Trend line; Stocker ADG = -39.62 + .021*(**Year**) + ε)

Several factors are possible contributors to the increased ADG from 1985-2015. Birthweights increased 1985-2015 (Figure 19). During the 1986 winter pasture trials at Overton, the average birthweight was 75.59 lbs. During the 2015 winter pasture trials at Overton, the average birthweight was 89.70 lbs. representing an increase of 13.11 pounds of birthweights over 30 years. Average birthweights were highest during years from 2005-2010.

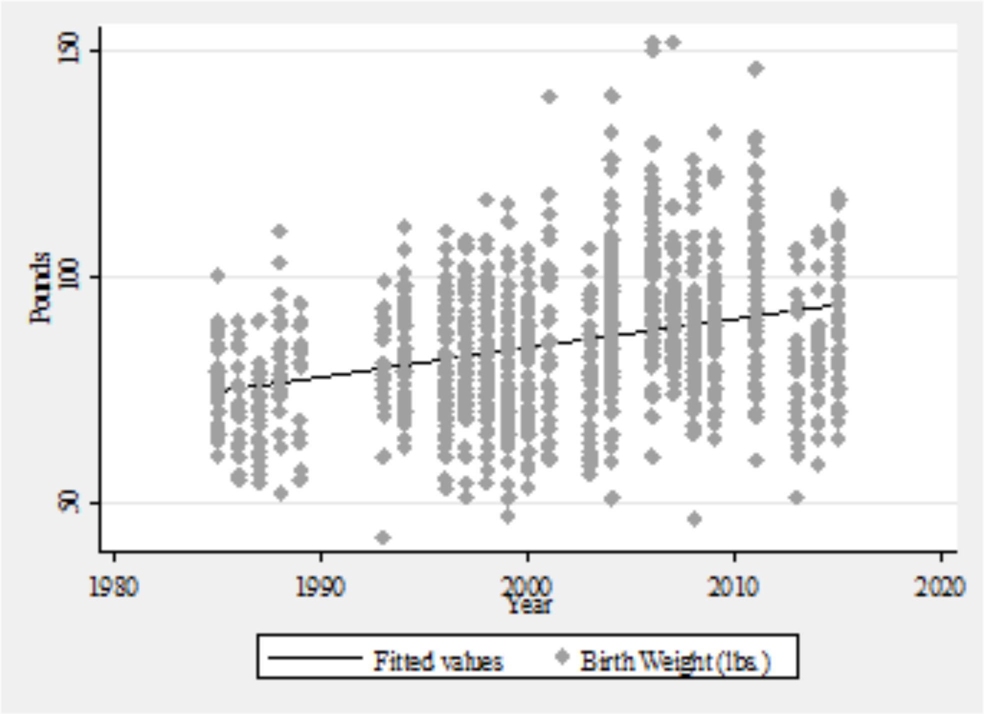

Figure 19. Stocker birth weight (1985-2015).
(Trend line; Stocker birth weight = -1203.04 + 0.644*(**Year**) + ε)

Preweaning growth (Figure 20) and weights at the beginning of stocking periods (Figure 21) have both increased while the age of cattle entering the stocking enterprise has remained relatively constant (Figure 22). Increased weight at the beginning of the stocking period associated with stable age of entry into the stocking enterprise year over year was likely a result of the increased birthweights and increased preweaning growth.

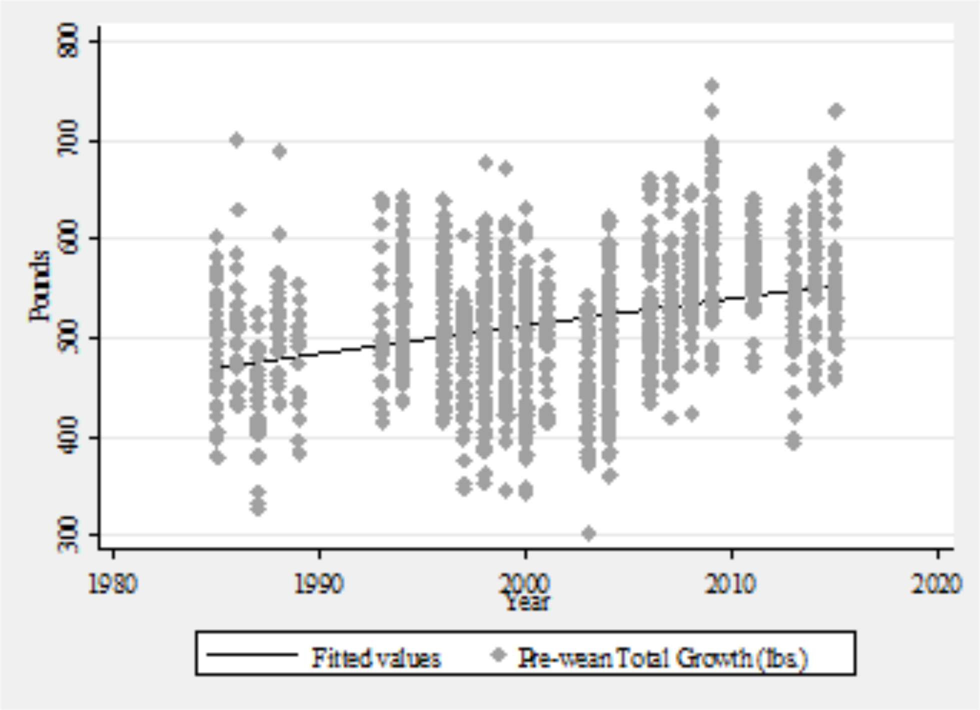

Figure 20. Pre-wean total growth (1985-2015).
(Trend line; Pre-wean total growth = -5050.94 + 2.781*(**Year**) + ε)

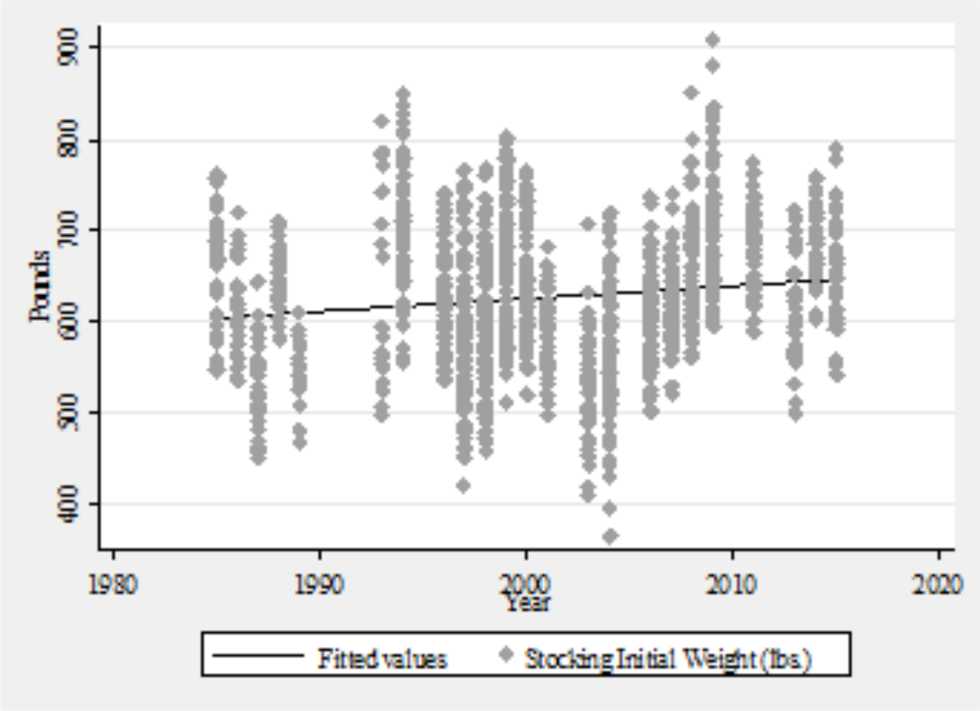

Figure 21. Stocker weight at begging of stocking period.
(Trend line; Initial weight = -2165.03 + 1.396*(**Year**) + ε)

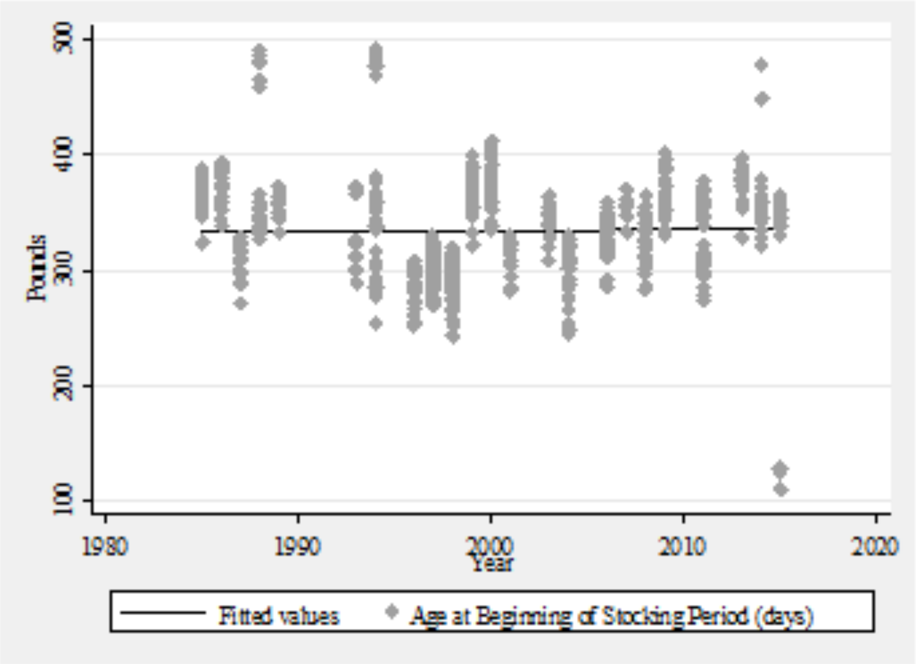

Figure 22. Stocker age at beginning of trial.
(Trend line; Stocker age at beginning of trial = 225.59 + 0.0544*(Year) + ε)

Terminal weights, the weight of the animals at the end of grazing, increased during the study period. Figure 23 illustrates the year over year increases in trial terminal weights.

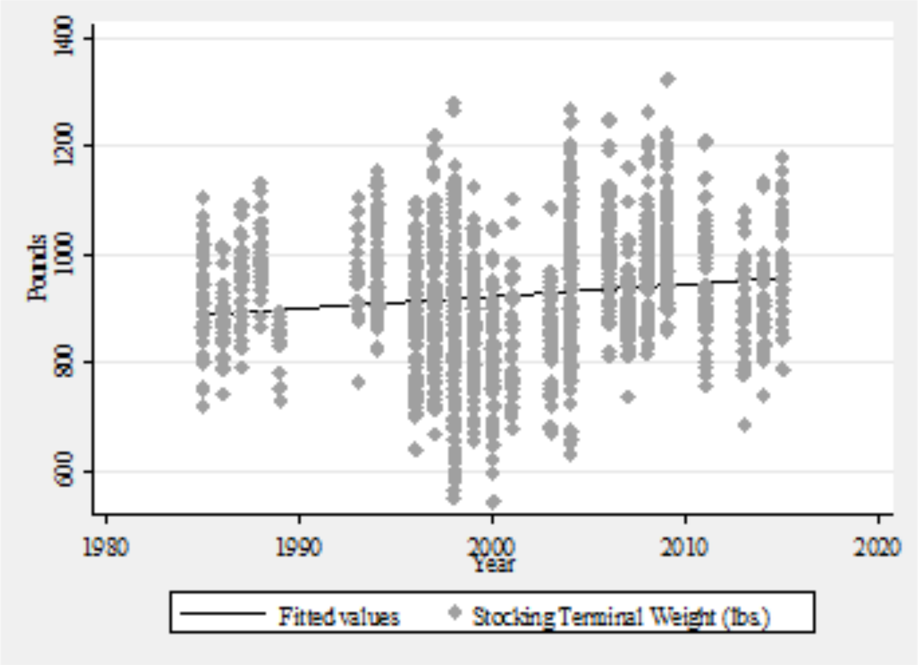

Figure 23. Stocker terminal weight
(Trend line; Stocker terminal weight = -3611.567 + 2.267*(**Year**) + ε)

Methodology

Numerous factors impact animal growth and, in turn, profitability. While many factors are under the control of management, temperature and precipitation are not. In order to determine the impact of changing precipitation and temperature over the study period, this research will focus on the impact of days on pasture (DOP), driven by temperature and precipitation, on animal growth and profitability.

During each year of data collection at the Texas A&M AgriLife Research & Extension Center at Overton, Texas, new data was collected from different individuals, representing a pooled cross section over time, and therefore cannot be assumed identically distributed to estimate under the same model. A Chow-test (equation 23) for a structural break in the data revealed a structural break between years 2000 and 2001.

$$Chow = \frac{(S_C - (S_1 + S_2))/k}{(S_1 + S_2)/((N_1 + N_2) - 2k)} \qquad \textbf{\textit{(23)}}$$

where S_c = Residual sum of squares, (1985-2015); S_1=Residual sum of squares, (1985-2000); S_2=Residual sum of squares, (2001-2015); N_1=651; N_2=631; k=18.

Considering the results of the Chow test for a structural break, an OLS regression was used to estimate each time period (1985-2000 and 2001-2015). Table 14 contains the results of each regression, where (dropped) indicates a variable that was dropped due to a significant degree of collinearity.

Table 14. Table of regression results for prediction of average daily gain (ADG)

	1985-2015			2001-2015			1985-2000		
	R^2		Adj. R^2	R^2		Adj. R^2	R^2		Adj. R^2
	0.456		0.451	0.458		0.45	0.424		0.415
Variable Name	Coef.	St. Err.	P	Coef.	St. Err.	P	Coef.	St. Err.	P
Female	-0.351	0.037	0	-0.328	0.047	0	-0.408	0.052	0
Weaning weight	0.006	0.001	0	0.007	0.001	0	0.001	0.001	0.418
Pre-wean ADG	-0.721	0.158	0	-1.164	0.313	0.001	-0.387	0.179	0.03
Weaning age (days)	-0.009	0.002	0	-0.01	0.003	0.002	-0.006	0.002	0.009
Initial weight	-0.002	0	0	-0.001	0.001	0.129	-0.001	0.001	0.112
Stocking rate	-0.492	0.025	0	-0.5	0.039	0	-0.501	0.034	0
Days on pasture	-0.014	0.001	0	-0.013	0.001	0	-0.011	0.001	0
Supplemented	0.891	0.078	0	0.809	0.079	0.005	0.529	0.184	0.004
Supplemented 4.0% BW/day	-0.315	0.109	0.004	-0.304	0.1	0.003		(dropped)	
Supplemented 1.0 lb./head/day	-0.583	0.197	0.003		(dropped)			(dropped)	
Supplemented 2.0 lb./head/day	-0.769	0.099	0		(dropped)		-0.194	0.191	0.309
Supplemented 4.0 lb./head/day	-0.496	0.104	0.003		(dropped)		-0.094	0.236	0.691
Intercept	7.136	0.426	0	6.62	0.728	0	7.295	0.544	0

In each regression, DOP was significant at the p=0.05 level, and displayed a negative relationship with ADG. As was discussed in the data section, total trial gain has remained constant or increased slightly 1985-2015. A negative relationship between DOP and ADG represents an increase in ADG required to maintain total trial gains over time as DOP decreased. Table 15 contains the results of regressions distributed along the same time periods as those in Table 14, where variables are used to estimate total stocker gain instead of ADG, where (dropped) indicates a variable that was dropped due to a significant degree of collinearity.

Table 15. Table of regression results for prediction of total stocker gain

	1985-2015			2001-2015			1985-2000		
	R^2		Adj. R^2	R^2		Adj. R^2	R^2		Adj. R^2
	0.395		0.389	0.48		0.472	0.387		0.377
Variable Name	Coef.	St. Err.	P	Coef.	St. Err.	P	Coef.	St. Err.	P
Female	-45.85	4.93	0	-37.25	5.9	0	-59.84	7.41	0
Weaning weight	0.639	0.1	0	0.788	0.18	0	0.085	0.139	0.545
Pre-wean ADG	-88.14	21.17	0	-127.8	39.363	0.001	-48.13	25.26	0.057
Weaning age (days)	-1.04	0.243	0	-1.18	0.398	0.003	-0.637	0.311	0.042
Initial weight	-0.246	0.052	0	-0.027	0.071	0.704	-0.165	0.081	0.041
Stocking rate	-51.96	3.4	0	-60.94	4.95	0	-53.62	4.76	0
Days on pasture	0.43	0.089	0	1.1	0.154	0	0.533	0.132	0
Supplemented	127.88	10.47	0.004	104.8.49	9.89	0	55.58	26.07	0.033
Supplemented 0.4% BW/day	-38.83	14.63	0.008	-39.8	12.61	0.002		(dropped)	
Supplemented 1.0 lb./head/day	-91.95	26.55	0.001		(dropped)			(dropped)	
Supplemented 2.0 lb./head/day	-108.9	13.36	0		(dropped)		-12.7	27.04	0.639
Supplemented 4.0 lb./head/day	-54.95	22.68	0.016		(dropped)		27.87	33.43	0.405
Intercept	594.4	57.32	0	446.68	91.6	0	660.54	77.77	0

Table 15 corroborates the idea of Figure 11 that total stocker gain increases as DOP increase. The rate at which stocker gains increase with additional DOP increased between 1985-2000 and 2001-2015.

Days on pasture were estimated with weather data from Henderson, Texas (Table 16) with weather variables significant to the growth of cool-season annual forages and bermudagrass.

Table 16. Table of regression results for prediction of days on pasture (DOP)

	1985-2015			2001-2015			1985-2000		
	R^2		Adj. R^2	R^2		Adj. R^2	R^2		Adj. R^2
	0.877		0.874	0.783		0.78	0.952		0.952
Variable Name	Coef.	St. Err.	P	Coef.	St. Err.	P	Coef.	St. Err.	P
Sep. Prec.	7.878	0.355	0		(dropped)		40.5	2.321	0
Oct. Prec.	2.45	0.686	0	-4.895	0.344	0		(dropped)	
Nov. Prec.	3.362	0.341	0	8.722	0.518	0	17.491	0.744	0
Dec. Prec.	-2.477	0.373	0		(dropped)		18.986	1.269	0
1st Quarter Prec.	-2.952	0.227	0		(dropped)		10.667	0.648	0
Aug. Avg. Max T.	-7.266	0.544	0	0.292	0.503	0.561	-0.573	0.577	0.321
Sep. Avg. Max T.	2.406	0.754	0.001		(dropped)			(dropped)	
Oct. Avg. Max T.	12.938	0.738	0		(dropped)			(dropped)	
Nov. Avg. Max T.	-5.605	0.81	0		(dropped)			(dropped)	
Dec. Avg. Max T.	-3.574	0.456	0	-1.748	0.523	0.001		(dropped)	
Jan. Avg. Max T.	-8.549	0.487	0	-3.092	0.53	0	18.472	1.074	0
Feb. Avg. Max T.	-0.456	0.045	0	-3.967	0.254	0	-2.157	0.135	0
Aug. Avg. Min T.	8.094	0.801	0		(dropped)			(dropped)	
Sep. Avg. Min T.	-4.473	0.785	0		(dropped)		-32.515	2.261	0
Oct. Avg. Min T.	-7.586	0.373	0	-3.302	0.235	0	-7.438	0.203	0
Nov. Avg. Min T.	2.262	0.551	0	-1.399	0.219	0	-4.082	0.239	0
Dec. Avg. Min T.	5.112	0.352	0	2.235	0.818	0.006	-26.943	1.909	0
Jan. Avg. Min T.	15.355	0.554	0	5.913	0.46	0		(dropped)	
Feb. Avg. Min. T.	-5.673	0.247	0		(dropped)		-25.598	1.656	0
Mar. Avg. Min T.	-1.062	0.353	0.003	-2.37	0.192	0		(dropped)	
Intercept	234.81	31.097	0	663.29	37.305	0	3382.9	156.45	0

Simulations of 36 scenarios of profitability uses the results of Table 15 and Table 16 to estimate final profit of a winter stocking system are shown in Table 17.

Table 17. Profitability scenarios simulated under designated assumptions of stocking rate, supplementation, and DOP

Scenario	Stock. Rate	Supplementation Amount	Years for dist. of DOP	Scenario	Stock. Rate	Supplementation Amount	Years for dist. of DOP
1	2.62	0	1985-2015	19	1.14	3	1985-2015
2	2.62	0	1985-2000	20	1.14	3	1985-2000
3	2.62	0	2001-2015	21	1.14	3	2001-2015
4	2.62	1	1985-2015	22	1.14	0.4% BW	1985-2015
5	2.62	1	1985-2000	23	1.14	0.4% BW	1985-2000
6	2.62	1	2001-2015	24	1.14	0.4% BW	2001-2015
7	2.62	3	1985-2015	25	4.1	0	1985-2015
8	2.62	3	1985-2000	26	4.1	0	1985-2000
9	2.62	3	2001-2015	27	4.1	0	2001-2015
10	2.62	0.4% BW	1985-2015	28	4.1	1	1985-2015
11	2.62	0.4% BW	1985-2000	29	4.1	1	1985-2000
12	2.62	0.4% BW	2001-2015	30	4.1	1	2001-2015
13	1.14	0	1985-2015	31	4.1	3	1985-2015
14	1.14	0	1985-2000	32	4.1	3	1985-2000
15	1.14	0	2001-2015	33	4.1	3	2001-2015
16	1.14	1	1985-2015	34	4.1	0.4% BW	1985-2015
17	1.14	1	1985-2000	35	4.1	0.4% BW	1985-2000
18	1.14	1	2001-2015	36	4.1	0.4% BW	2001-2015

Each scenario was simulated using Texas A&M AgriLife Extension’s November 2018 Estimated Costs and Returns to November-May Stockers budget for the North Texas Extension District – 4 (Bennet, 2018), shown in Appendix A. The simulation maintained the assumptions of the budget in Appendix A with the exception of stocker purchase and sale weight and price, the gain contract, and bermudagrass hay. The gain contract in the Texas A&M AgriLife Extenion budget was eliminated.

Bermudagrass hay was replaced with supplemental ration fed in different amounts. The supplemental ration, based on the data provided by Texas A&M AgriLife Research & Extension Center at Overton, TX could include a mixture of ingredients including corn, molasses, soybean meal, dried molasses, Rumensin ®, Bovatec ®, GainPro ®, amino acids, and gluten. No specific ingredient was intended as a variable of evaluation by this study, only the strategy of supplementation in general. The ration was priced using the current value of corn, $125.00/ton, and was either withheld or fed in one of three different daily amounts; one pound per head, three pounds per head, 0.40% of bodyweight.

All characteristics of cattle and market conditions were simulated using the coefficients shown in Table 14 for the period 2001-2015, except for DOP, which was simulated under three different periods. Table 18 shows the levels for each variable used in the simulation.

Table 18. Table of variable levels for estimation of total stocking gain

Variable Name	Value used for simulation of profit
Female	0 (indicates steer)
Weaning weight	Multivariate empirical distribution of 2001-2015 data
Pre-wean ADG	Multivariate empirical distribution of 2001-2015 data
Weaning age (days)	Multivariate empirical distribution of 2001-2015 data
Initial weight	Multivariate empirical distribution of 2001-2015 data
Stocking rate	Set based on Scenarios in Table 9
Days on pasture	Estimated using multivariate empirical distribution of precipitation and temperature data for 1985-2015, 1985-2000, 2001-2015
Supplementation	Varied based on scenario
Intercept	615.12

The simulation assumes 200 steers, with no gains from specific breed type, supplemented with a mixed ration, under three stocking rates, and distributions of the other variables in Table 15, including DOP estimated with the results of Table 16.

Table 18 shows that DOP were estimated using a multivariate distribution of precipitation and temperature data for 1985-2015, 1985-2000, 2001-2015. Precipitation and temperature data for Henderson, Texas, located near the Texas A&M AgriLife Research and Extension Center at Overton, Texas were obtained from the National Oceanic and Atmospheric Administration (NOAA) (National Oceanic and Atmospheric Administration, 2018). Days on pasture were then estimated using those data and the regression results provided in Table 16. Days on pasture were adjusted to reflect the average number of DOP 1985-2015, the number of DOP from 1985-2000, and 2001-2015 to provide an indication of the impact weather-driven changing DOP have had on profitability.

Weaning weight, pre-wean ADG, weaning age, and initial weight were simulated under a multivariate empirical distribution using the data from 2001-2015 from the Texas A&M AgriLife Research and Extension Center at Overton, Texas, and provided stochastic values for the initiation of the simulation, where initial weight is the same as purchase weight. Cattle purchase and sale price were estimated using an empirical distribution of Oklahoma National Stockyard medium and large frame steer prices, at 50 lb. increments from 300 lbs. – 1,200 lbs., provided by Livestock Marketing Information Center (LMIC) (Livestock Marketing Information Center, 2018). Animals were priced based on their weight at purchase and their weight at the end of the stocking period. Final revenue of the system came from the sale price ($/cwt) of feeder steers multiplied by the weight per steer, multiplied by the number of steers.

Results

Profitability varied based on supplementation strategy, stocking rate, and estimated DOP. Table 19 shows the summary statistics of simulated profit for scenarios

1-36. The highest mean profit from the stocker enterprise, $10,065, for 200 steers, was a result of the conditions under Scenario 26 in which there was no supplementation, a stocking rate of 4.1 animals/acre, and days on pasture was estimated from the period 1985-2000, i.e. longer days on pasture. The lowest mean profit from the stocker enterprise, $(10,503), per 200 steers, was a result of the conditions under Scenario 21, in which cattle were provided supplementation at a rate of 3 lbs./head/day, there was a stocking rate of 1.14 animals/acre, and days on pasture estimated for the period 2001-2015, i.e. shorter days on pasture.

Table 19. Summary statistics of profit simulation for scenarios 1-36

	1985-2015	1985-2000	2001-2015	1985-2015	1985-2000	2001-2015
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Mean	$6,757	$9,776	$4,792	$502	$2,784	($889)
Std. Dev.	$74,752	$75,586	$70,715	$74,988	$76,405	$73,473
Min	($195,536)	($206,576)	($196,930)	($215,477)	($214,126)	($216,394)
Max	$246,089	$257,191	$238,546	$252,449	$263,945	$244,638
	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Mean	($6,561)	($6,788)	($9,465)	($5,521)	($2,581)	($8,000)
Std. Dev.	$78,275	$79,228	$76,908	$78,921	$79,259	$77,145
Min	($212,439)	($208,967)	($219,049)	($217,129)	($209,503)	($224,165)
Max	$265,168	$277,452	$256,822	$261,067	$273,098	$252,894
	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18
Mean	$5,719	$8,738	$3,754	($536)	$1,747	($1,927)
Std. Dev.	$74,752	$75,586	$70,715	$74,988	$76,405	$73,473
Min	($196,574)	($207,613)	($197,967)	($216,515)	($215,164)	($217,432)
Max	$245,051	$256,154	$237,508	$251,411	$262,907	$243,600
	Scenario 19	Scenario 20	Scenario 21	Scenario 22	Scenario 23	Scenario 24
Mean	($7,599)	($7,826)	($10,503)	($6,559)	($3,619)	($9,038)
Std. Dev.	$78,275	$79,228	$76,908	$78,921	$79,259	$77,145
Min	($213,477)	($210,005)	($220,086)	($218,167)	($210,540)	($225,203)
Max	$264,130	$276,414	$255,784	$260,030	$272,060	$251,856
	Scenario 25	Scenario 26	Scenario 27	Scenario 28	Scenario 29	Scenario 30
Mean	$7,046	$10,065	$5,081	$791	$3,074	($600)
Std. Dev.	$74,752	$75,586	$70,715	$74,988	$76,405	$73,473
Min	($195,247)	($206,286)	($196,640)	($215,188)	($213,837)	($216,105)
Max	$246,378	$257,480	$238,835	$252,738	$264,234	$244,927
	Scenario 31	Scenario 32	Scenario 33	Scenario 34	Scenario 35	Scenario 36
Mean	($6,272)	($6,499)	($9,176)	($5,232)	($2,292)	($7,711)
Std. Dev.	$78,275	$79,228	$76,908	$78,921	$79,259	$77,145
Min	($212,150)	($208,678)	($218,760)	($216,840)	($209,213)	($223,876)
Max	$265,457	$277,741	$257,111	$261,357	$273,387	$253,183

Maximum-mean indicates that an increase in DOP increases mean profit from the stocking enterprise. In all 12 pairs of scenarios with the same assumptions but for the distribution of DOP, profit from the scenario with longer days on pasture exceeded profit from the scenario with shorter days on pasture. In certain cases, profit doubled from changing only the distribution of DOP.

Maximum profit indicates that increased DOP increases maximum profit from the stocking enterprise. In all 12 sets of scenarios with the same assumptions but for the distribution of DOP, maximum profit from the scenario with longer days on pasture exceeded profit from the scenario with shorter days on pasture. A shorter distribution of DOP is accompanied by a negative expected mean profit in nine of 12 scenarios with the shorter distribution of DOP.

There is a clear pattern in profit from the interaction between stocking rate, and the amount of supplementation provided. The six scenarios which provide the most profit did not provide a supplement. Within that grouping, the higher the stocking rate, the greater the expected mean profit was, and the longer distribution of DOP was always associated with a higher mean profit than the shorter distribution of DOP. The second set of six ranked scenarios, i.e. the seventh most profitable scenario to the twelfth most profitable scenario, followed the exact same pattern as the six most profitable scenarios, except that the cattle were provided with a supplemental ration at the rate of 1lb./head/day. With each incremental increase in supplementation, profitability decreased.

Cumulative distribution functions (CDFs) of profit with the same supplementation strategies and stocking rates, with varying DOP (1985-2000 and 2001-2015) are shown in Figure 24 – Figure 26. The CDFs show that there is little difference in simulated profit under different DOP, and CDFs usually cross, indicating different highest profit at different probability levels.

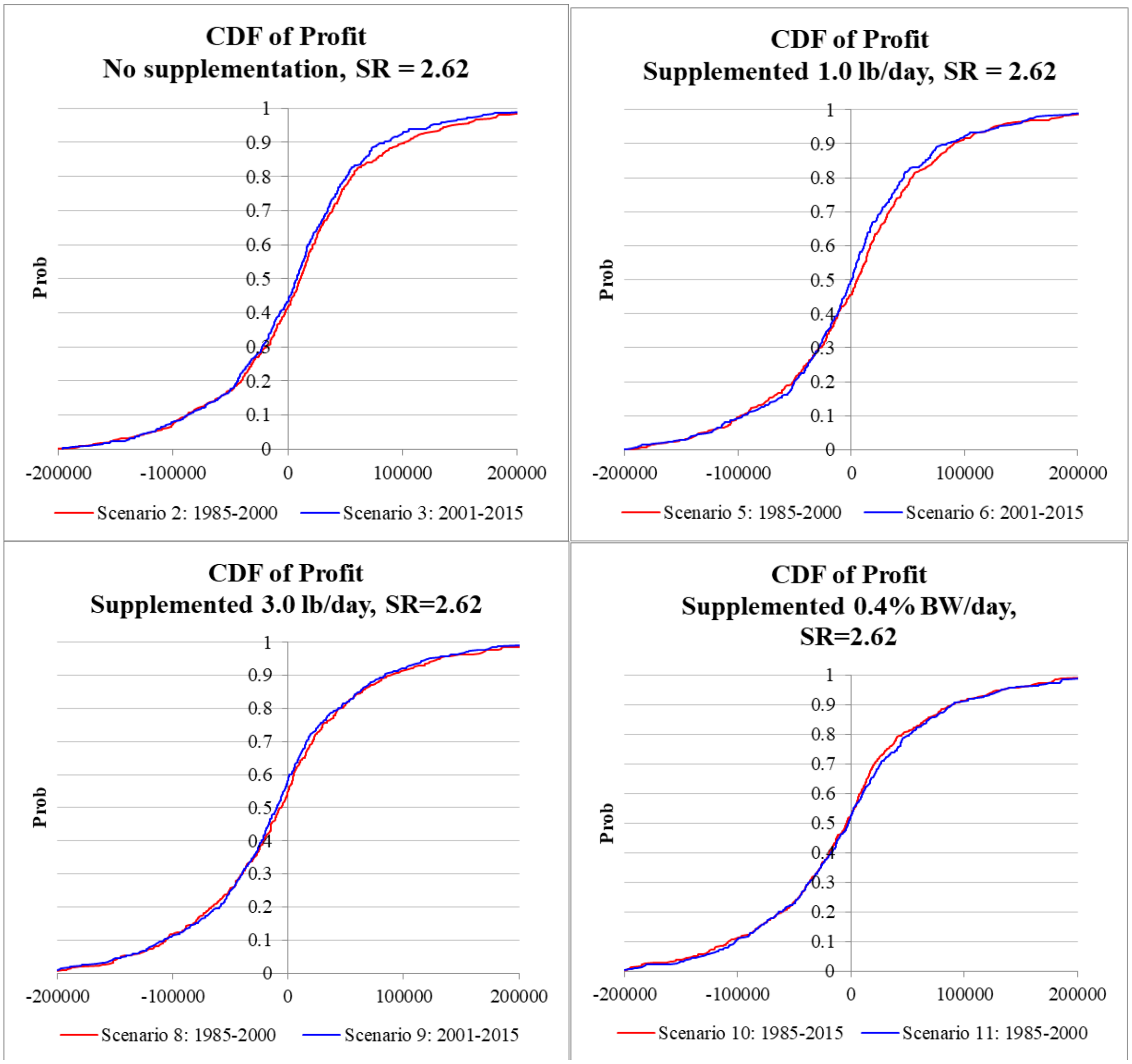

Figure 24. Cumulative distribution function (CDF) of profit of scenarios (1985-2000) and (2001-2015) with stocking rate (SR) = 2.62

Figure 24 does not show a clear difference in the scenarios on each graph of CDFs and in most cases the CDFs cross, making the most profitable choice unclear.

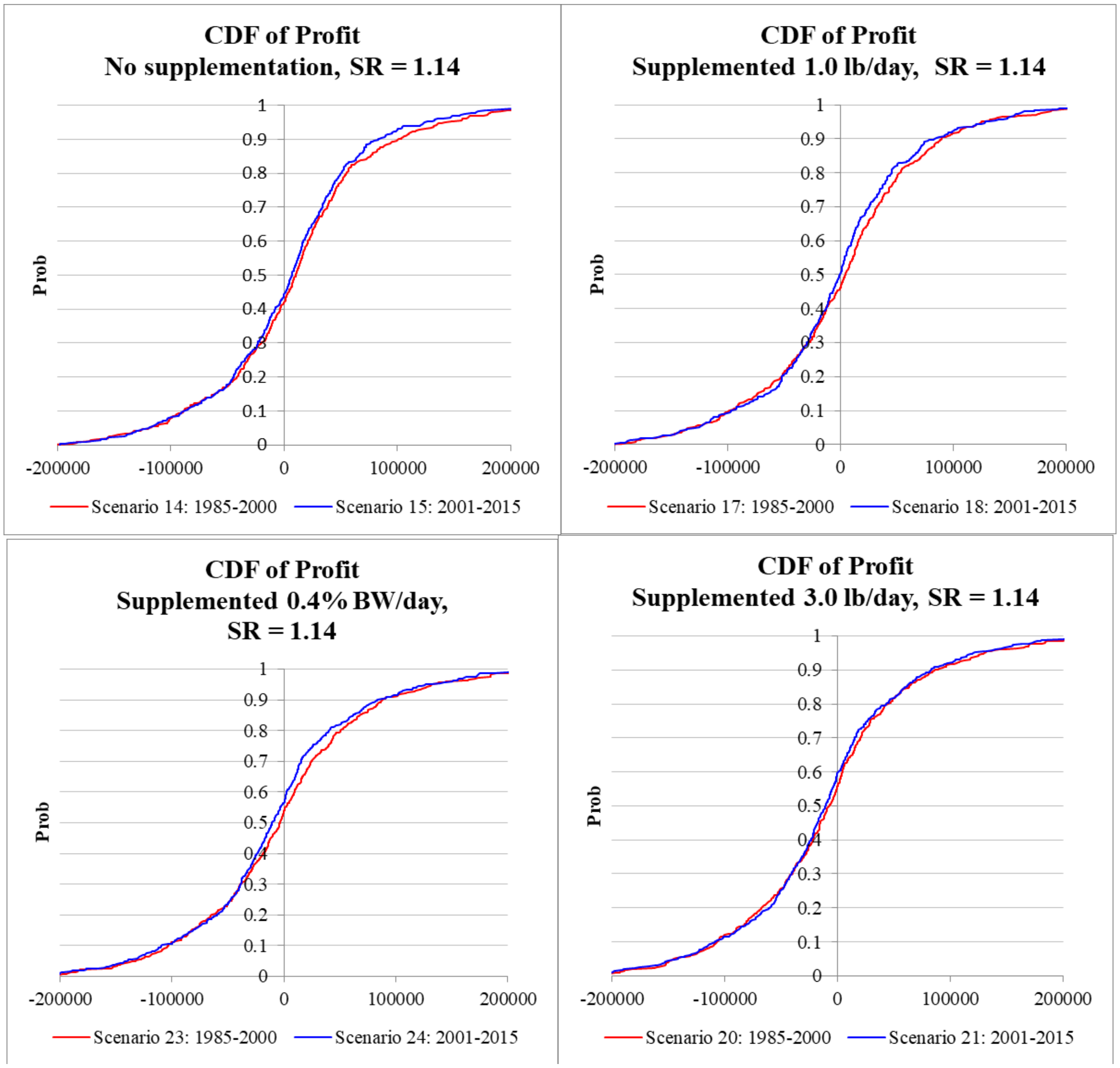

Figure 25. Cumulative distribution function (CDF) of profit of scenarios (1985-2000) and (2001-2015) with stocking rate (SR) = 1.14

Figure 25 does not show a clear difference in the scenarios on each graph of CDFs and in most cases the CDFs cross, making the most profitable choice unclear.

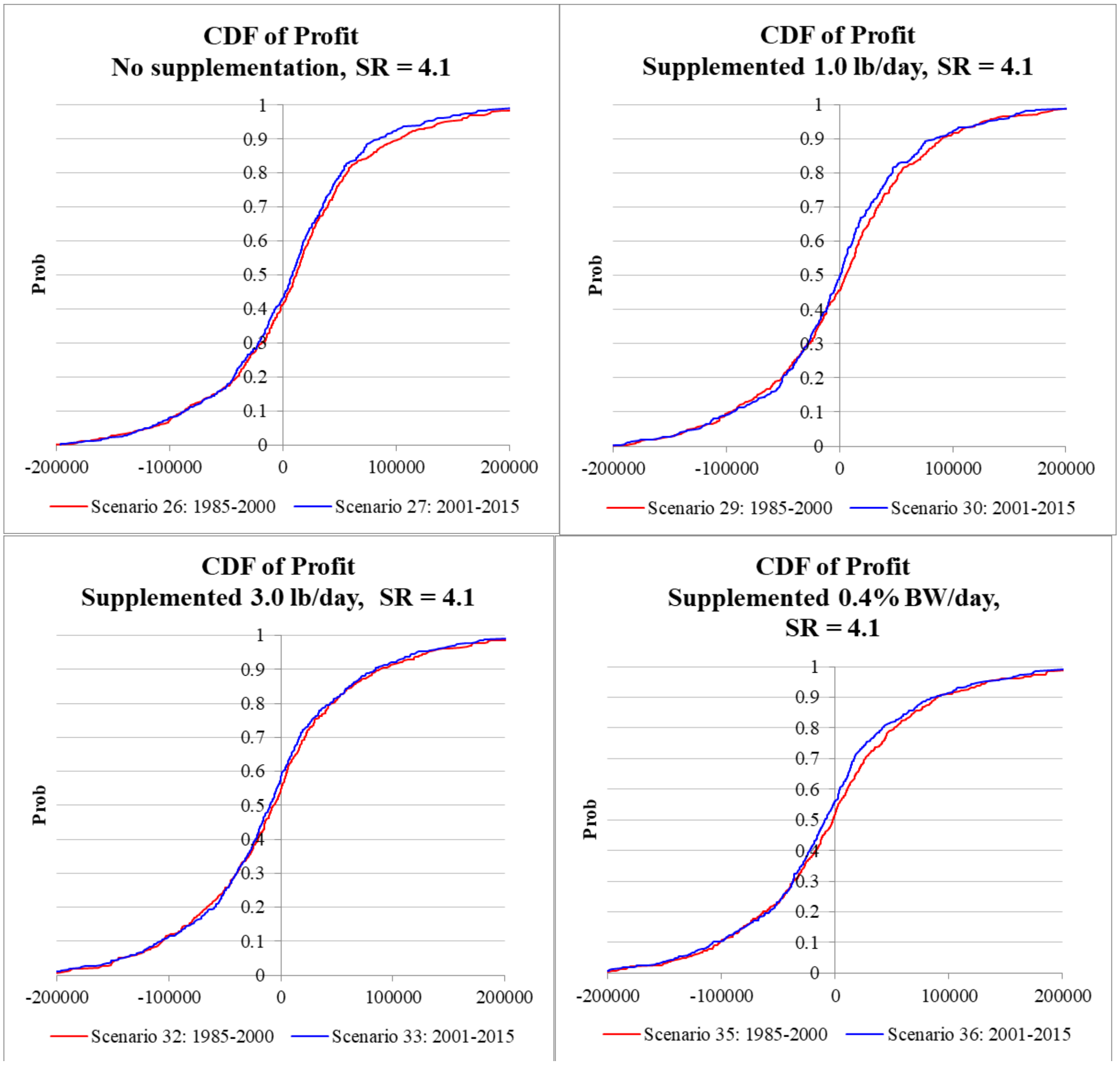

Figure 26. Cumulative distribution function (CDF) of profit of scenarios (1985-2000) and (2001-2015) with stocking rate (SR) = 4.1

Figure 26 does not show a clear difference in the scenarios on each graph of CDFs and in most cases the CDFs cross, making the most profitable choice unclear.

The case-by-case CDFs in Figure 24-Figure 26 do not provide significant insight into the difference in scenarios, however Figure 19, CDFs of Scenario 26 and Scenario 21, the scenarios with the highest expected profit most and least expected profit, respectively, shows a significant difference in outcomes. Scenario 21 presents with approximately a 60.0% chance of negative returns, almost 20.0% greater than the chance of negative returns from Scenario 26. The CDFs for Scenarios 21 and 26 also do not cross, and so there is a definitive, overall more profitable scenario when comparing the two.

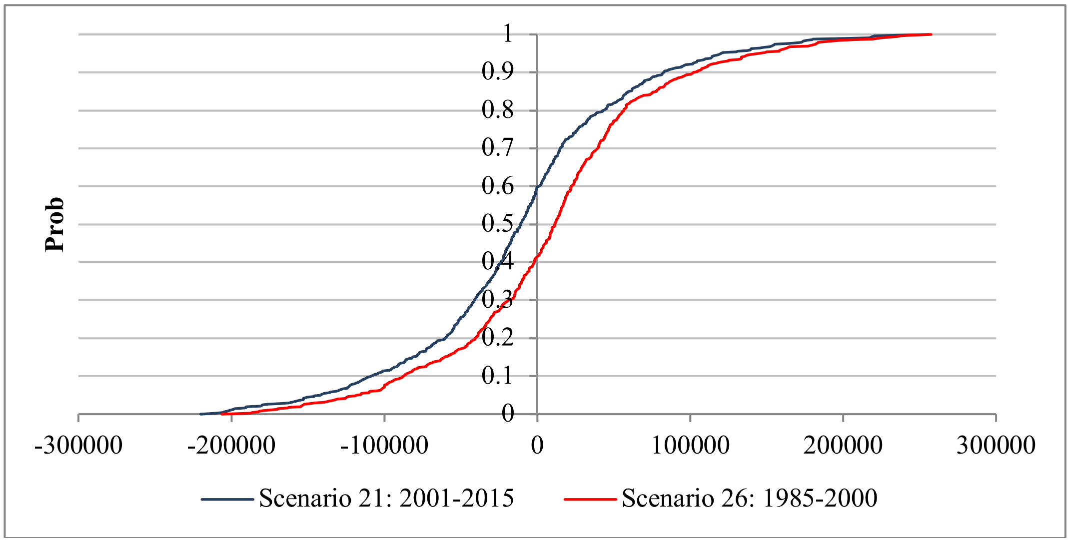

Figure 27. Cumulative distribution function (CDF) of profit of scenarios Scenario 26 and Scenario 21

A CDF that lies entirely to the right of another CDF indicates a more profitable scenario, however when CDFs cross other methods must be employed to determine the ‘best’ scenario. Stochastic dominance with respect to a function (SDRF) with a risk aversion coefficient (RAC) 0.0 was used to rank scenarios from most preferred to least preferred. Scenario 26 remains the most preferred scenario using SDRF. The most profitable scenarios employ a strategy of no supplementation, and within each level of supplementation longer DOP and higher stocking rates yield higher profit.

Table 20. Analysis of Stochastic Dominance with Respect to a Function (SDRF) of stocker profitability scenarios (1985-2000) and (2001-2015)

Risk Aversion Coefficient = 0

Scenario name	Level of Preference
Scenario 26: 1985-2000	Most Preferred
Scenario 2: 1985-2000	2nd Most Preferred
Scenario 14: 1985-2000	3rd Most Preferred
Scenario 27: 2001-2015	4th Most Preferred
Scenario 3: 2001-2015	5th Most Preferred
Scenario 15: 2001-2015	6th Most Preferred
Scenario 29: 1985-2000	7th Most Preferred
Scenario 5: 1985-2000	8th Most Preferred
Scenario 17: 1985-2000	9th Most Preferred
Scenario 30: 2001-2015	10th Most Preferred
Scenario 6: 2001-2015	11th Most Preferred
Scenario 18: 2001-2015	12th Most Preferred
Scenario 35: 1985-2000	13th Most Preferred
Scenario 11: 1985-2000	14th Most Preferred
Scenario 23: 1985-2000	15th Most Preferred
Scenario 32: 1985-2000	16th Most Preferred
Scenario 8: 1985-2000	17th Most Preferred
Scenario 36: 2001-2015	18th Most Preferred
Scenario 20: 1985-2000	19th Most Preferred
Scenario 12: 2001-2015	20th Most Preferred
Scenario 24: 2001-2015	21st Most Preferred
Scenario 33: 2001-2015	22nd Most Preferred
Scenario 9: 2001-2015	23rd Most Preferred
Scenario 21: 2001-2015	Least Preferred

Conclusions

“Opportunities for adaptation are shaped by the operating context within which decision making occurs” (Walthall et al., 2013). The three goals of this research were to determine the most profitable stocking strategies available for East Texas stocker enterprises, whether or not changing temperature and precipitation impact DOP, and if so what the impact of changing temperature and precipitation are having on profitability of East Texas stocker enterprises. Within the context of the variables significant to estimating ADG and total gain in the data provided by F.M.Rouquette, Jr, Texas A&M AgriLife Research at the Texas A&M AgriLife Research & Extension Center at Overton, Texas over a 30+ year period the decisions available to grazing managers included stocking rate, supplementation strategies, and DOP.

Scenario 26 was the most profitable scenario under all methods of evaluation. Stockers are were not provided a supplement, stocked at a rate of 4.1 animals/acre, and DOP are distributed according to data from 1985-2001, which on average indicates longer DOP than the period 2001-2015.

The results of this study indicate that the cost of excessive supplementation may exceed the returns gained from the practice. Supplementing with corn has been shown to increase ADG, however the cost associated with the gains from supplementation in the data from the Texas A&M AgriLife Research & Extension Center at Overton, Texas appear to outweigh the profit from those gains. The positive relationship between stocking rate and increased profit follows the logic that, the more animals that can be grazed on a unit of land, the more profit will be captured from that land from increased total weight gain.

Along with Scenario 26, the top scenarios in all combinations with similar management characteristics expect for DOP yield more profit when the distribution of DOP is longer, i.e. simulated using the data from 1985-2001. The longer animals are able to gain weight, the more profit will be derived from the stocking system, as long as costs do not increase dramatically.

The high explanatory power ($R^2 = 0.877$) of precipitation and temperature variables in predicting DOP, and the significance of time in the estimation of precipitation and temperature (Figure 13 – Figure 16) indicate that changing temperatures are impacting DOP, which are decreasing over time (Figure 12). In fact, from the first period (1985-2000) to the second period (2001-2015) producers in East Texas have lost approximately 20 days, over two weeks, of grazing-days.

Precipitation in September, October, and November is positively related to the number of DOP, however since 1985 precipitation in each of those months has declined significantly. Precipitation in December and the first quarter of each year are negatively related to the number of DOP, and precipitation in those periods has decreased significantly over time, potentially offsetting the losses in DOP from decreased precipitation in earlier fall months. Maximum temperature in September, October, and minimum temperature in August, December, and January are significantly positively related with DOP. Maximum temperature in December and February have increased and minimum temperature in December and January have decreased since 1985, and have led to a decrease in DOP.

The final goal of this research was to determine whether or not decreasing DOP, driven by changing temperature and precipitation, decreases profit. Simulated scenarios of profitability, varying DOP under constant management strategies otherwise, typically leads to more profit. While the differences in profitability between scenarios are not always large, increasing DOP tends to increase profitability.

It is possible that the impact of decreased DOP over time might be more pronounced, were it not for the exogenous increases in cattle size over time. However, when size is held constant more DOP still provide more profit than fewer DOP. The result of the simulation in this research make clear that decreasing DOP, estimated using temperature and precipitation data, lead to lower profit, and DOP have decreased significantly since 1985.

The data from the Texas A&M AgriLife Research at the Texas A&M AgriLife Research & Extension Center at Overton, Texas provides a host of opportunities for further research. Incorporating more weather and climate variables such as the Palmer Drought Index into estimates of DOP could increase the reliability of the estimation of DOP. In addition to the data provided, there is similar data from the Texas A&M AgriLife Research at the Texas A&M AgriLife Research & Extension Center for a cow-calf enterprise, and data for the stockers exists through the cut-out stage. Utilizing similar methods to determine the impact of climate on DOP would benefit cow-calf producers and to determine the impact of climate-driven DOP on cut-out values, and for the entire cattle and beef industry.

Studying Figure 11 and Figure 12 suggests a decrease in total gain over time, however Figure 17 shows an increase in total trial gain over time. Further studying the attributes of animals included in the study to determine the source of increased total gain, despite a significant decrease in DOP, would lend further accuracy to the findings of this study.

Incorporating forecasted temperature, precipitation, and other climate variables would allow the establishment of a long-term forecast of eastern Texas stocker profitability. In addition, varying death rates based on incremental climatic change and extreme events would create a more realistic study.

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CHAPTER III CONCLUSION

THE VALUE OF A COMBINATION ARC AND PLC PROGRAM

Introduction

The 2014 Farm Bill allowed producers to elect their farms into either Price Loss Coverage (PLC) or Agricultural Risk Coverage (ARC). PLC was designed to protect producers in an environment of low prices while ARC was designed to protect producers in an environment of declining revenues.

Both ARC and PLC are market-oriented risk management policies that were intended to decrease government outlays on commodity programs and eliminate direct decoupled payments to producers (Campiche et al., 2014; Shields, 2015). A decline in prices since the 2014 Farm Bill ballooned spending in the ARC and PLC programs from \$5 billion on 2014's production to almost \$7 billion on 2015 and 2016's production each, with outlays of over \$4 billion annually projected for crop years 2016-2027 (Angadjivand, 2017).

It is likely that the 2018 Farm Bill will likely allow producers to change their enrollment from ARC to PLC or vice versa (Zulauf et al., 2017). Alternative strategies to changing enrollment have been suggested, including weighted enrollment in both programs, i.e. 50.0% of base acres in ARC and 50.0% of base acres in PLC (Zulauf et al., 2017). In the Agriculture Act of 2014, producers were allowed to enroll their farm, on a crop by crop basis, in either ARC or PLC. For example, under the Agriculture Act of 2014, if a producer grew 100 acres of corn, all 100 acres were enrolled in either ARC or PLC for the life of the farm bill. The proposed blended program that is the subject of this study would allow that same producer to enroll 50 of those corn base acres in ARC and 50 of the corn base acres in PLC.

The purpose of this study is to evaluate the expected revenue of the proposed combination commodity support program for corn, soybeans, grain sorghum, wheat, barley, oats, seed cotton, and peanuts for payment years 2018-2024. These eight crops amount to approximately 98.0% of all non-generic base acres in the US (Farm Service Agency, 2015). This study utilizes FSA county level data for all counties with base in barley, corn, grain sorghum, peanuts, oats, seed cotton, soybeans, and wheat to determine expected revenue, including expected commodity program payments, for those crops. This study shows which of the original commodity support programs or what mixed program has the highest expected revenue in each county with non-irrigated base acreage in one of the previously described 8 crops. Additionally, this study will use the difference in outcomes of each of the existing commodity support programs and the theoretical mixed program to determine the mixed program's value.

Literature Review

History

The history of modern United States (US) farm policy has been a sustained movement away from government-backed price supports and supply controls toward a market-oriented support system (Dimitri et al., 2005; Shields, 2015). Prior to the 1920s farm policy was focused on different goals. The origin of support for agriculture in the late 1700s was a series of policies aimed at expanding agriculture to newly acquired territories (Effland, 2000) followed by an increase in the quality of producer education, technological development, and eventually market information tools and infrastructure services (Effland, 2000).

Following World War II, demand for US produced food fell as the rest of the world re-entered production agriculture and domestic prices fell (Effland, 2000). The New Deal dictated a more direct role of government intervention in markets and production decisions by farmers in order to provide support for an industry that was characterized by small, diverse farms primarily selling domestically (Dimitri et al., 2005; Doering and Outlaw, 2006). Beginning with the passage of the Agricultural Adjustment Act (AAA) farm policy has used various methods of direct market intervention to achieve different goals in the agricultural sector (Taylor et al., 2017). Doering and Outlaw (2016) describe the historic goals of farm policy as, first, supporting commodity prices as a percentage of parity, then supporting producer incomes at a politically acceptable level, and finally making US agricultural policy more responsive to market forces.

Pressed by the rising cost of commodity programs and the need to appease international trade requirements, a transition in the 1990s led to the replacement of price supports and supply controls with direct payments based on historic production (Effland, 2000; Dimitri et al., 2005; Angadjivand, 2018). Since that time, direct payments to producers have iteratively moved towards market signal-based direct payments to producers and a risk-management oriented approach to agricultural support (Shields, 2015; Angadjivand, 2018).

Throughout their evolution, farm policy critics have held that commodity supports transfer risk from producers to taxpayers, encourage production on land that otherwise would go untouched, and cause market distortion (Shields, 2015). However, there are a host of rationales for government intervention in farm policy. In the New Deal era, a goal of commodity programs was to raise rural standards of living, the state of 25.0% of the US population, to that of urban communities (Doering and Outlaw, 2006 ; Shields, 2015). Since that time domestic food security, risk reduction from natural causes, industry stability, and conservation have been held up as rationales for, and benefits of commodity policy.

Current commodity programs

The 2014 Farm Bill allowed producers to select their farms into either Price Loss Coverage (PLC) or Agricultural Risk Coverage (ARC) in a one-time irrevocable decision through the next farm bill or, potentially, the extension of the 2014 Farm Bill. The programs represented a sweeping change to farm policy and replaced direct payments, moving towards a policy of risk management (Campiche et al., 2014; Farm Service Agency, 2014). The rationale behind the new programs was to reduce the deficit by eliminating decoupled payments not tied to declining prices or farm loss (Shields, 2015).

The ARC program provides revenue loss protection for producers in two formats (FSA, 2014; Campiche et al., 2014; Taylor et al., 2017). Agricultural Risk Coverage - County Level (ARC-CO) provides revenue loss protection based on a county-level yields and a national marketing year average (MYA) price and not on producers actual crop production. ARC-CO guarantees 86.0% of a county's benchmark revenue where the calculation is the same for all base acres of a crop in a county (Campiche et al., 2014; Taylor et al., 2017). Benchmark revenue is equal to the previous five-year Olympic average of county yield times the previous five-year Olympic MYA price. In ARC-CO, payments are determined on a crop by crop basis, not across an entire farm and payments are made on 85.0% of that crop's base acreage.

Agricultural Risk Coverage – Individual Level (ARC-IC) provides a safety net for producers based on their individual crop production. Producers enroll in ARC-IC on a whole-farm basis, regardless of the variety of crops in production on that farm and the payment calculation is slightly different. Producers enrolled in ARC-IC are required to provide FSA information on crops grown on their base acres and farm-level yields and prices received (Taylor et al., 2017). Payments from ARC-IC are determined by calculating revenue across all crops reported and comparing that revenue to a five-year Olympic average of that producers weighted per-acre revenue, with payments based on 65.0% of base acres, not 85.0% as in ARC-CO (Taylor et al., 2017). Both ARC-CO and ARC-IC payments are capped at 10.0% of benchmark revenue.

The third commodity program provide by the 2014 Farm Bill is Price Loss Coverage (PLC), a program similar to the counter-cyclical payment (CCP) in the 2008 Farm Bill with significantly higher reference prices replacing CCPs target prices (Campiche et al., 2014). Base acres are enrolled by commodity as with ARC-CO and payments are eligible on 85.0% of base acres. PLCs payment is the difference between the reference price and the effective price (the higher of the marketing year price or loan rate) when the reference price exceeds the effective price, multiplied by payment yield and the 85.0% coverage rate (Campiche et al., 2014). Producers enrolled in PLC have the option to enroll in the Supplemental Coverage Option (SCO) on the same acreage as a complement to a producer's individual insurance policy. SCO is designed to cover the difference between 86.0% and the level of coverage on producer's insurance policy, with SCO premiums subsidized at 65.0% by the United States Department of Agriculture (USDA). SCO is beneficial to producers that normally produce low levels of coverage due to cost that are commonly located in high-risk areas and in need of additional assistance (Taylor et al., 2017).

Enrollment in ARC and PLC varied by crop and region, with less than 1.0% of producers enrolling base acreage in ARC-IC (FSA ARC/PLC Election Data, May 2015). In total, producers enrolled 242,355,208 base acres in non-generic base acreage (Farm Service Agency, 2015). Record high prices in certain commodities directly preceding the enrollment period led to different enrollment patterns around the country (Taylor et al., 2017). Figure 1 represents the percent of base acres enrolled in either ARC-CO or PLC as of May 2015.

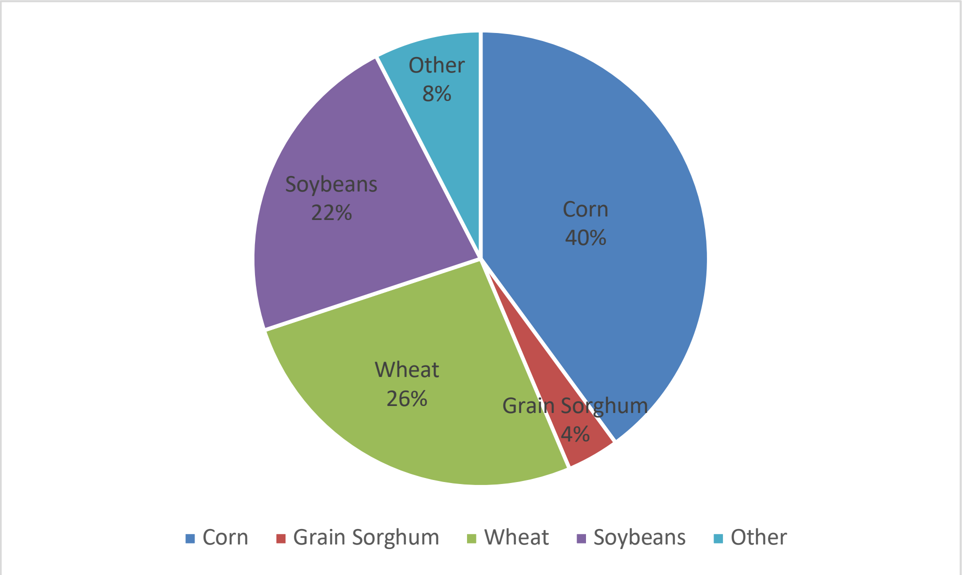

Figure 28. Percent of Base Acres by Commodity
Source: FSA ARC/PLC Election Data, May 2015

Figure 28 represents the percent of base acres in each of several major commodities enrolled in ARC-CO and PLC during the 2014-2018 farm bill enrollment.

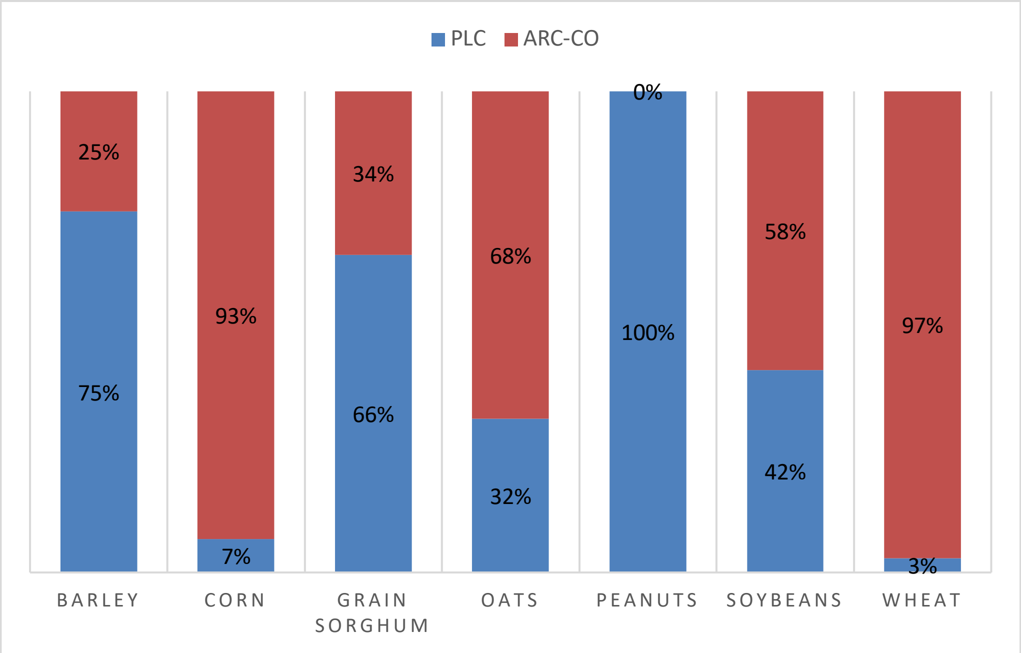

Figure 29. Percent of base acres in ARC and PLC by commodity for eight largest base acre crops
Source: FSA ARC/PLC Election Data, May 2015

Figure 29 shows that base acre enrollment in each of the three largest commodities in terms of base acres, ARC-CO enrollment exceeded 50.0%. Historic revenues experienced during the life of the 2008 Farm Bill, the period used to establish benchmark revenues for the 2014 Farm Bill, is what led producers of corn and soybeans to enroll heavily in ARC-CO under the expectation of higher payments than PLC (O'Donoghue and Hungerford, 2016; Taylor et al., 2017; Angadjivand, 2018). Since enrollment, the price of both corn and soybeans has seen significant reduction. Producers of peanuts and rice, crops whose price hovered around the newly proposed reference prices during the period used to establish historic price patterns, primarily enrolled in PLC under expectations of greater support from high fixed reference prices (Taylor et al., 2017). Wheat was the only major crop to experience relatively balanced enrollment; 42.0% in ARC-CO and 56.0% in PLC.

Payments to program crops vary. Under the 2014 Farm Bill most of the outlays for commodity support programs between 2014-2016 are attributable to corn (46.0%), wheat (16.0%), soybeans (15.0%), rice (5.0%), and peanuts (4.0%) (Schnepf, 2017). The vast majority ($10.3 billion or 75.5%) of the outlays in PLC from the 2014-2016 crop years are attributable to corn while the majority ($1.6 billion or 31.9%) of payments in ARC-CO were directed to wheat (Zulauf et al., 2018). Average program payments for corn from the 2014-2016 crop years were $80/acre for corn, and $25/acre for wheat and soybeans (Taylor et al., 2017).

Proposed changes to commodity programs

Expected payments from ARC are decreasing as each year of decreased prices is incorporated into payment calculations and PLC payments are expected to increase or remain constant as prices remain lower than statutorily set references prices (Richardson et al., 2017). Recommendations for restructuring commodity support programs run the gamut. In 2016's "Options for Reducing the Deficit: 2017 to 2026," Director Hall of the Congressional Budget Office (CBO) recommends several strategies related to commodity support programs for reducing the deficit. Strategies suggested include eliminating commodity support programs and limiting payments to 50.0% of base acres instead of 85.0%.

Under current levels of farm stress these solutions would likely prove disastrous. Farm incomes have dropped drastically since the signing of the 2014 Farm Bill resulting in a similar situation to the 1980s farm crisis (Outlaw et al., 2017). Rather than program elimination or benefit reduction other programs have recommended programs that update ARC-CO historic yield formulation (Taylor et al., 2017; Angadjivand, 2018) or allowing mixed base acre enrollment (Zulauf et al., 2017).

The Bipartisan Budget Act of 2018 authorized Seed Cotton as a covered commodity under the ARC/PLC commodity programs of the 2014 farm bill. During the 2014 farm bill cotton was eliminated as a covered commodity due to trade disputes with Brazil in the World Trade Organization (WTO). The new farm bill will continue the seed cotton program, allowing enrollment in ARC and PLC. The Bipartisan Budget Act of

2018 designates seed cotton, a combination of both cotton lint and cottonseed as a covered commodity.

To be eligible for enrollment of seed cotton in a commodity program, producers must have generic base acers, formerly upland cotton base acres prior to the 2014 farm bill. FSA reported over 19 million base acres in 2016 that will now be eligible for enrollment of seed cotton.

Data & Methodology

Expected revenue calculation

In order to determine the program of choice for each commodity in different counties with base acre history, each expected revenue outcome was simulated from 2019-2023 per base acre. This study strictly reviews expected revenues, including expected program payments, for FSA program crops under the non-irrigated, otherwise known as dryland, practice in order to prevent inappropriate comparisons under FSA-designated "all-practice" counties. Expected revenue from production is:

$$E[Revenue] = E[Price] * E[Yield] \tag{25}$$

Farms qualify for payments under PLC when:

$$Effective\ price < Reference\ price \tag{26}$$

where the effective price is the greater of the national marketing year average price or the national average loan rate. The national marketing year average price for a covered commodity is determined annually by USDA and was obtained from FSA program data. The national average loan rate is the national average loan rate for marketing assistance loans in the 2014 farm bill and was obtained from FSA program data.

The statutory reference price, needed for calculating PLC payments, is set in the 2014 farm bill and the Bipartisan Budget Act of 2018 for seed cotton. Table 20 shows the statutorily established reference prices for the crops in this study.

Table 21. – Reference prices for selected commodities.

	Reference Price	Unit
Barley	\$4.95	Bushel
Corn	\$3.70	Bushel
Grain sorghum	\$3.95	Bushel
Oats	\$2.40	Bushel
Peanuts	\$535.00	Ton
Seed Cotton	\$0.36	Pound
Soybeans	\$8.40	Bushel
Wheat	\$5.50	Bushel

The payment rate when a PLC payment is provided is:

$$Payment\ rate = reference\ price - effective\ price \tag{27}$$

The national average loan rate represents the lowest effective price possible. Payment rates do not increase beyond the difference in the reference price and national average loan rate, even if real prices are below the national average loan rate. The total payment per base acre is:

$$Payment\ Amount = payment\ rate * payment\ yield \tag{28}$$

The payment yield for PLC payments is established by FSA and was obtained for each county studied from FSA program data.

Farms qualify for ARC-CO payments when:

$$Actual\ crop\ revenue < ARC\ guarantee \tag{29}$$

The ARC guarantee is a base level of revenue designed as a safety net and calculated by:

$$ARC\ guarantee = 0.86 * Benchmark\ revenue \tag{30}$$

where the benchmark revenue is:

$$\begin{aligned} &Benchmark\ revenue \\ &\quad = 5\ year\ Olympic\ marketing\ year\ average\ price \\ &\quad * 5\ year\ Olympic\ average\ county\ yield \end{aligned} \tag{31}$$

Both the marketing year average price and average county yields are established by USDA and were obtained from FSA program data, where available, and supplemented with National Agricultural Statistics Service (NASS) data where necessary.

Actual crop revenue is obtained by:

$$\begin{aligned} &Actual\ crop\ revenue \\ &\quad = Average\ county\ yield \\ &\quad * \ max\begin{cases} national\ marketing\ year\ average\ price \\ \qquad national\ average\ loan\ rate \end{cases} \end{aligned} \tag{32}$$

The payment rate when an ARC payment is provided is the lesser of the amount that the ARC guarantee for the year exceeds the actual crop revenue or 10.0% of the benchmark revenue for the crop year. Both ARC and PLC are subject to a limitation on total annual program payments of $125,000, including any loan deficiency payments (LDPs), to any one producer or legal entity.

The mixed base acreage option evaluated as a third choice by this study is calculated as:

$$\begin{aligned} &Mixed\ base\ acreage\ payment \\ &= (\alpha)(ARC - CO\ payment) \\ &+ (1-\alpha)(PLC\ payment) \\ &\alpha \in (0,1) \end{aligned} \tag{33}$$

In the case of this study, α=0.5. Each program payment was simulated using a Latin Hypercube sampling procedure of 500 iterations to obtain a sum of commodity program revenues from 2019-2023.

The Food and Agricultural Policy Research Institute (FAPRI) provides a ten-year baseline forecast of major commodity prices. Table 21 contains FAPRI's crop prices from 2018-2023 as of the August 2018 Baseline Update.

Table 22. FAPRI August 2018 Baseline Update for U.S. Agricultural Markets selected crop prices

		September – August year				
Crop	Unit	2018/2019	2019/2020	2020/2021	2021/2022	2022/2023
Barley	Bushel	$4.61	$4.75	$4.80	$4.79	$4.76
Corn	Bushel	$3.62	$3.83	$3.85	$3.87	$3.85
Grain sorghum	Bushel	$3.34	$3.68	$3.60	$3.58	$3.55
Oats	Bushel	$2.82	$2.58	$2.67	$2.67	$2.67
Peanuts	Ton	$442.40	$418.20	$423.60	$441.40	$441.40
Seed Cotton	Pound	$0.752	$0.712	$0.710	$0.698	$0.702
Soybeans	Bushel	$8.73	$8.95	$9.29	$9.39	$9.23
Wheat	Bushel	$5.12	$5.11	$5.16	$5.21	$5.16

Expected revenues from production and payments were forecast on a county-by-county basis using a payment forecast program in Python developed by Dr. Henry

Bryant. The program uses official ARC yields and National Agricultural Statistics Service (NASS) yields to linearly project historic yields, where official ARC yield history is unavailable. Similarly, the program uses FSA prices to establish a historic price series where FSA data is available. If official FSA prices are not available FAPRI prices are used, and NASS price data is used when the first two choices are unavailable.

Dependent on FAPRI price projections, the payment forecast program generates 500 possible price draws, to forecast price for a specified period of time. In the case of this study five years from 2019-2023 are chosen. Using the 500 possible price draws and forecasted assumed yields at the county level the payment forecast program generates expected revenue from production for the specified time period. Additionally, each of the 500 possible revenue outcomes are evaluated using the payment formulas for ARC, PLC, and the blend to generate expected revenue from production and commodity program payments.

Expected revenue comparison

In addition to describing expected revenue from production and commodity program payments, this study utilizes certainty equivalents to determine the value of the ability to enroll in a blended commodity program.

The utility of a payment, i.e. the subjective internal value attached to a payment, is the appropriate measure to rank monetary outcomes (Mas Colell, 1995); however, ranking the expected utility of revenues from production and ARC, PLC, or the blend only provides an ordinal ranking of the options, not the magnitude by which expected revenues from enrollment in one program exceeds expected revenues from the others. A certainty equivalent provides a cardinally comparable, risk-adjusted expected revenue for each program.

A utility function must be chosen to obtain a certainty equivalent. A logarithmic utility function is used for its risk aversion properties:

$$u(x) = \ln(x) \tag{34}$$

This study assumes producers choosing between existing commodity programs and the proposed blend are risk averse and assumes the logarithmic utility function. The logarithmic utility function exhibits constant relative risk aversion (CRRA). Under CRRA, no matter the wealth of the individual at different points in time, the portfolio decisions of an individual in terms of budget share do not change (Mas Colell, 1995). The class of CRRA utility functions eliminates income effects when making decisions about risk as a proportion of an agent's wealth, simplifying comparisons across wealth levels.

A certainty equivalent (CE) utilizes the utility function of an economic agent to determine the monetary payment an economic agent would be willing to accept for certain to attain the same utility as a lottery with an uncertain outcome (Mas Colell, 1995). For a given revenue forecast, expected utility is:

$$\begin{gathered} u\big(CE(Expected\ Total\ Revenue)\big) = \sum_{x \epsilon X} p(x)u(x) \\ x\ \epsilon\ (Revenue + ARC, Revenue + PLC, Revenue + Blend) \end{gathered} \tag{35}$$

where *p(x)* is the probability of outcome *x*, and *u(x)* is the utility from the given outcome. Substituting equation 34 into equation 35, yields:

$$ln\big(CE(Expected\ Total\ Revenue)\big) = \sum p(x) \ln{(x)}$$

$$x \in (Revenue + ARC, Revenue + PLC, Revenue + Blend) \tag{36}$$

Solving equation 36 for *CE(Expected Total Revenue)* yields:

$$CE(Expected\ Total\ Revenue) = e^{\sum_{x \in X} p(x) \ln(x)}$$

$$x \in (Revenue + \{ARC, PLC, Blend\}) \tag{37}$$

Obtaining the certainty equivalent of each program provides a risk adjusted value that can be used to compare programs cardinally. After annual revenue for each of the years from 2019-2023 is obtained, the expected revenue was discounted then summed in order to obtain the present value of the certainty equivalent ($PV[CE]$) for each expected revenue stream:

$$PV[CE] = \sum_{t}^{t+5} e^{-rt} CE(Expected\ Total\ Revenue_t) \tag{38}$$

where t=2018 and r = 0.02. This study uses the expected PVCE for comparison and ranking of commodity programs.

Results

Table 22 contains summary statistics of $PV[CE]$ for expected revenue from production and commodity program payments by crop 2018-2023. In all crops, $PV[CE]$ is highest for PLC. A higher CE means that an agent must receive more money for certain in order to avoid participating in the uncertain outcome than a lower expected CE. Therefore, Table 22 clearly shows that, on average, PLC is preferred in terms of $PV[CE]$ across all crops, even when the blend is available. However, given that the Table 22 provides the $PV[CE]$ summed over 2018-2023, a period of five years, the difference in average $PV[CE]$ between the blend and the existing program of choice may not be substantially different. In fact, in all crops except for peanuts the difference in $PV[CE]$ for PLC does not exceed $PV[CE]$ for the blend by more than 5.0%. In soybeans, the difference in average $PV[CE]_{PLC}$ and average $PV[CE]_{Blend}$ of the blend, 2018-2023, is less than half a percent.

At the maximum expected $PV[CE]$, the difference between the blend and PLC, the existing program that had the highest maximum $PV[CE]$ in every crop, becomes even smaller in all crops but soybeans and wheat. The difference in the maximum $PV[CE]_{Blend}$ and $PV[CE]_{PLC}$ remained the same in soybeans and wheat as the difference in the average $PV[CE]$ for the blend and PLC. In soybeans and barley, the minimum $PV[CE]_{Blend}$ in at least one county was higher than the $PV[CE]_{PLC}$. Table 22 tells us that, on average, PLC nets a higher expected $PV[CE]$ for all crops, however this statement must be evaluated across individual counties.

Table 23. Summary statistics of the present value of the certainty equivalent ($PV[CE]$) ($/acre) of expected revenue from production and commodity program payments by crop 2018-2023

	Barley ($/bu.)			Corn ($/bu.)		
	Blend	ARC	PLC	Blend	ARC	PLC
Average	$928.78	$900.69	$954.85	$1,921.58	$1,883.58	$1,957.18
Max	$1,815.80	$1,778.44	$1,851.99	$4,021.93	$3,983.71	$4,059.44
Min	$102.99	$90.43	$96.57	$260.28	$245.32	$260.80
Std. Dev.	$356.80	$354.29	$360.97	$753.10	$751.92	$756.05
C.V.	38.40%	39.30%	37.80%	39.20%	39.90%	38.60%
	Grain Sorghum ($/bu.)			Oats ($/bu.)		
	Blend	ARC	PLC	Blend	ARC	PLC
Average	$1,006.39	$952.97	$1,056.71	$514.48	$500.69	$527.36
Max	$1,873.35	$1,812.55	$1,948.61	$903.36	$884.03	$922.08
Min	$291.31	$258.44	$320.88	$210.52	$196.97	$220.11
Std. Dev.	$439.62	$436.40	$444.74	$157.24	$156.42	$158.41
C.V.	43.70%	45.80%	42.10%	30.60%	31.20%	30.00%
	Peanuts ($/ton)			Seed Cotton ($/lb.)		
	Blend	ARC	PLC	Blend	ARC	PLC
Average	$3,407.74	$3,088.45	$3,770.36	$2,383.23	$2,306.35	$2,456.39
Max	$5,829.94	$5,575.76	$6,082.14	$4,506.56	$4,410.90	$4,600.44
Min	$751.02	$546.59	$948.90	$634.84	$600.25	$666.63
Std. Dev.	$978.05	$1,018.14	$1,020.65	$843.99	$831.48	$857.21
C.V.	28.70%	33.00%	27.10%	35.40%	36.10%	34.90%
	Soybeans ($/bu.)			Wheat ($/bu.)		
	Blend	ARC	PLC	Blend	ARC	PLC
Average	$1,460.38	$1,456.68	$1,463.39	$901.85	$854.50	$945.73
Max	$2,514.47	$2,503.69	$2,524.65	$1,743.99	$1,668.69	$1,826.42
Min	$626.96	$627.99	$625.55	$171.49	$149.31	$182.05
Std. Dev.	$469.36	$468.66	$470.28	$345.31	$343.04	$349.29
C.V.	32.10%	32.20%	32.10%	38.30%	40.10%	37%

Table 23 shows results on a more county by county basis. Table 23 shows:

$$PVCE_{Blend} - Max\ \{PVCE_{ARC}, PVCE_{PLC}\} \tag{39}$$

Table 23 also shows how many counties in each crop would attain the maximum $PV[CE]$ from each of ARC, PLC, or the blend. Negative values in the top panel of Table 23 represent conditions in which the $PV[CE]_{Blend}$ for the blend does not exceed the expected $PV[CE]$ for the existing two commodity programs. If the maximum expected $PV[CE]$ of the blend is not positive, it means that the blend does not provide the highest expected $PV[CE]$ of the three programs in any county for that crop.

Table 24. Amount by which present value of the certainty equivalent (PV[CE]) of the blended plan exceeds the maximum PVCE of the existing commodity programs; Count of counties by program with maximum *PV[CE]*.

	Amount by which PVCE(Blend) > Max PVCE{ARC, PLC)							
	Barley	Corn	Grain Sorghum	Oats	Peanuts	Seed Cotton	Soybeans	Wheat
Average	$(26.08)	$(35.59)	$(50.32)	$(12.89)	$ (362.62)	$ (73.16)	$ (5.53)	$(43.88)
Max	$ 6.43	$ 17.54	$(25.37)	$ (2.54)	$ (197.49)	$ (6.06)	$ 1.00	$(10.56)
Min	$(41.56)	$(67.79)	$(95.31)	$(22.86)	$(1,270.21)	$ (121.68)	$(20.94)	$(91.40)
Std. Dev.	$ 8.94	$ 16.11	$ 17.61	$ 4.68	$ 162.92	$ 27.39	$ 4.68	$ 13.63
C.V.	34.3%	45.3%	35.0%	36.3%	44.9%	37.4%	84.5%	31.1%

	Count of counties by program with maximum(PVCE)							
	Barley	Corn	Grain Sorghum	Oats	Peanuts	Seed Cotton	Soybeans	Wheat
ARC	0	0	0	0	0	0	47	0
PLC	62	221	113	128	42	114	89	169
Blend	1	2	0	0	0	0	8	0

While Table 22 shows that PLC, on average, provides the highest $PV[CE]$ across all crops, results show slightly more variation at the county level. In particular, the blend provides the highest expected PVCE for soybeans in eight cases, and ARC provides a higher $PV[CE]$ in 47 cases. The smallest range between $PV[CE]$ of revenue from the blend per acre and the $PV[CE]$ of revenue from the $Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\}$ occurs in soybeans. This represents the small range between expected ARC and PLC payments 2018-2023. In counties growing soybeans where the blend provides the highest expected $PV[CE]$ over the 2018-2023 period, the blend would 'replace' ARC as the best option in five counties, and 'replace' PLC as the best option in three counties. For both corn and barley, the counties the blend would 'replace' would both achieve the highest expected $PV[CE]$ through enrollment in PLC in the absence of the blended plan.

Figure 30 through Figure 37 map the results of equation 39 by crop at the county level. A positive value represents a case in which the $PV[CE]_{Blend}$ exceeds $Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\}$. Figure 30 is a map of the results of equation 39 for barley. Compared to other crops the range by which $PV[CE]_{PLC}$, the preferred plan, exceeds the $PV[CE]_{Blend}$ is relatively small. One county in Texas that produces non-irrigated barley has a $PV[CE]_{Blend}$ than the $Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\}$, meaning that expected revenue in that county would increase as the result of creating a blended plan.

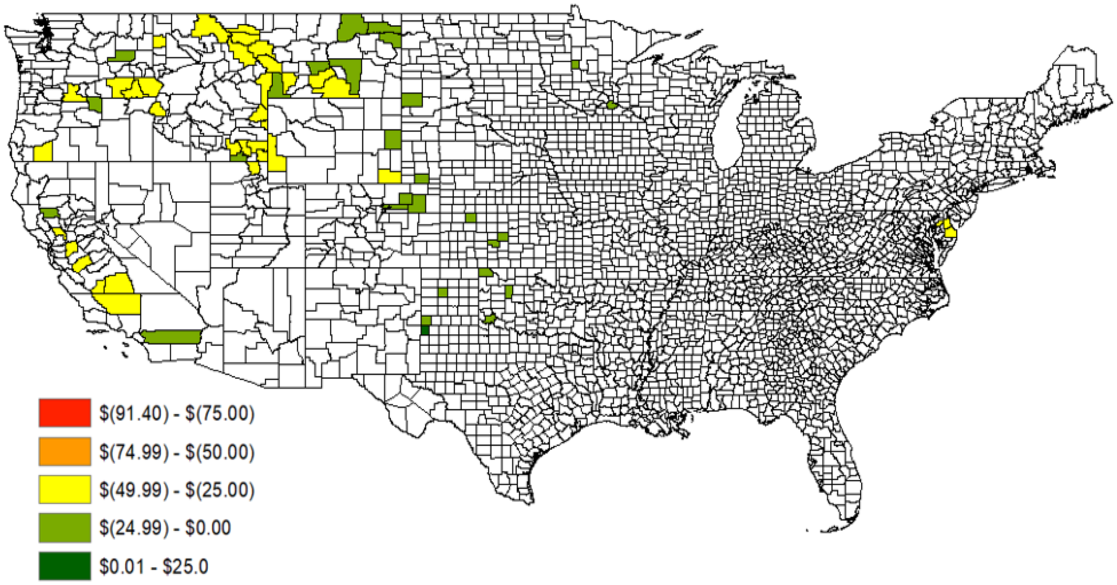

Figure 30. U.S. county map of ($PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\}$), non-irrigated barley

Figure 31 is a county map of the results of equation 39 for corn. The range of the results from equation 39 is greater for corn than for barley. The greater range is potentially a result of more data available and production across a more diverse geography. The $PVCE_{PLC}$ exceeds the $PVCE_{Blend}$ by the greatest amount in Nebraska and Kansas, two of the top ten corn producing states by total volume (USDA ERS, 2018).

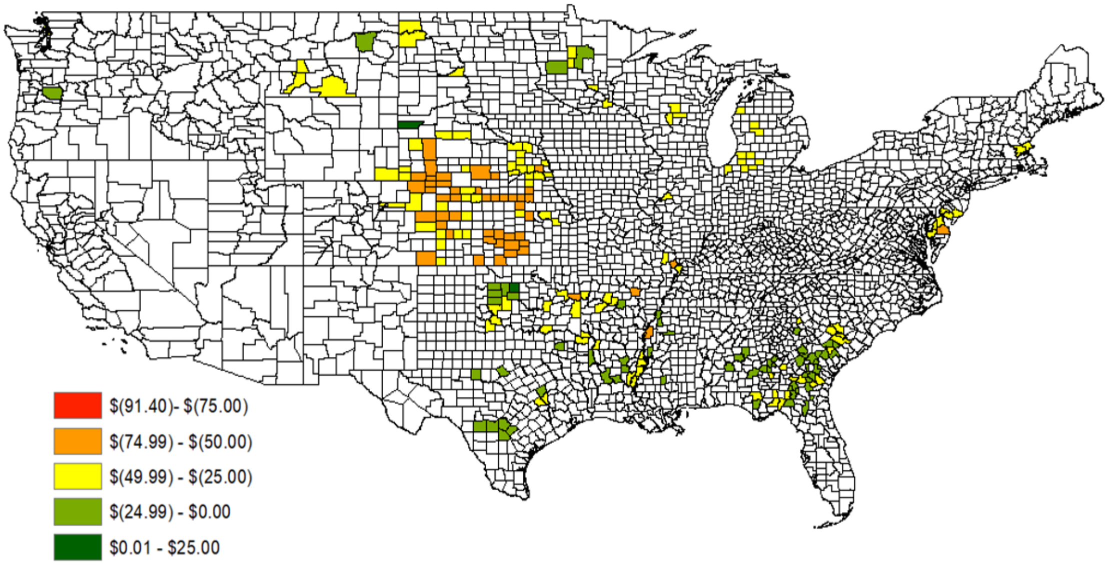

Figure 31. U.S. county map of $(PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\})$, non-irrigated corn

Figure 32 is a county map of the results of equation 39 for non-irrigated grain sorghum. Grain sorghum represents 4.0% of base acre enrollment (Figure 1). Unlike the result of equation 39 for corn, in no county does the result of equation 39 exceed $(25.00) for grain sorghum.

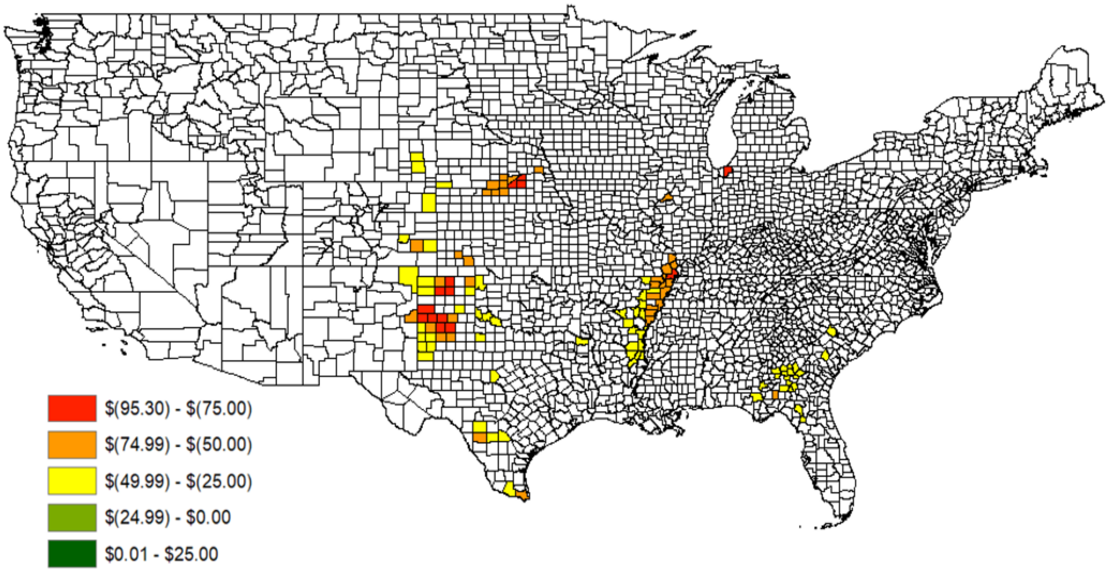

Figure 32. U.S. county map of $(PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\})$, non-irrigated grain sorghum

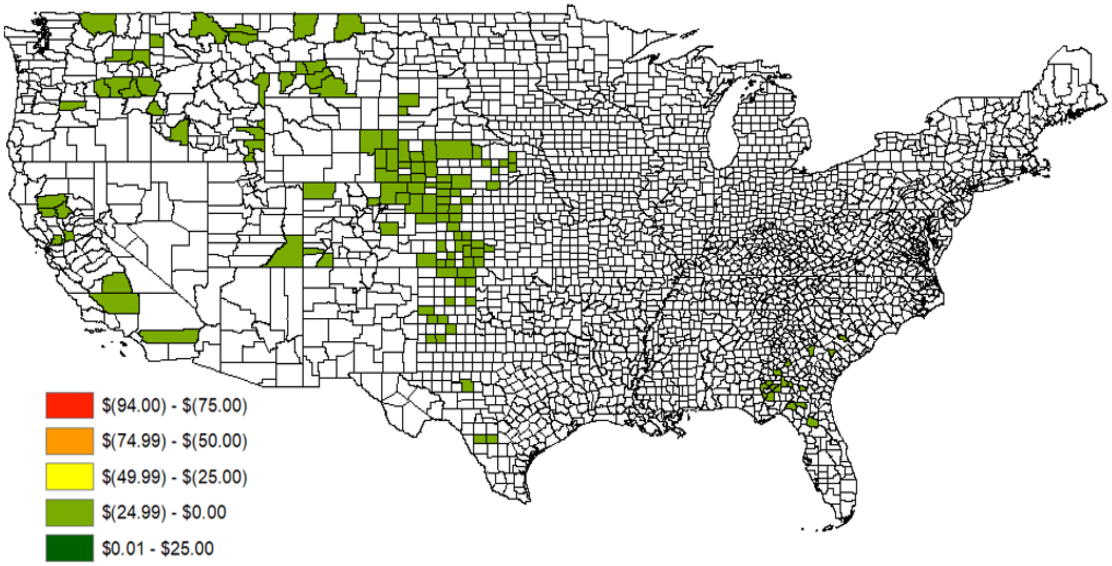

Figure 33. U.S. county map of $(PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\})$, non-irrigated oats

Figure 33 is a county map of the results of equation 39 for non-irrigated oats. The results of equation 39 are most consistent county-to-county for oats. For all counties, the difference in $PV[CE]_{Blend}$ and $PVCE_{PLC}$ does not exceed $25.00/acre.

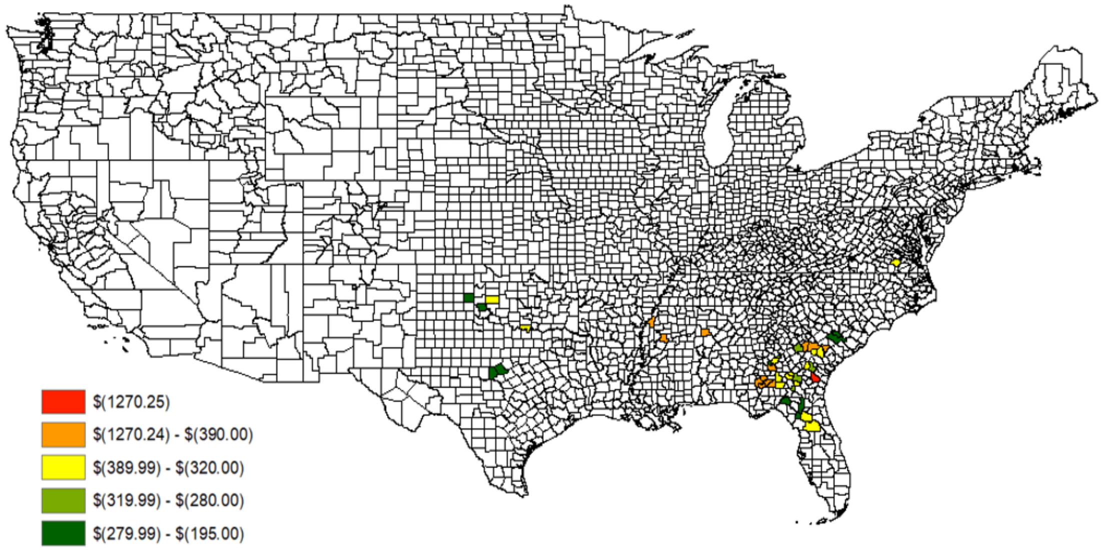

Figure 34. U.S. county map of $(PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\})$, non-irrigated peanuts

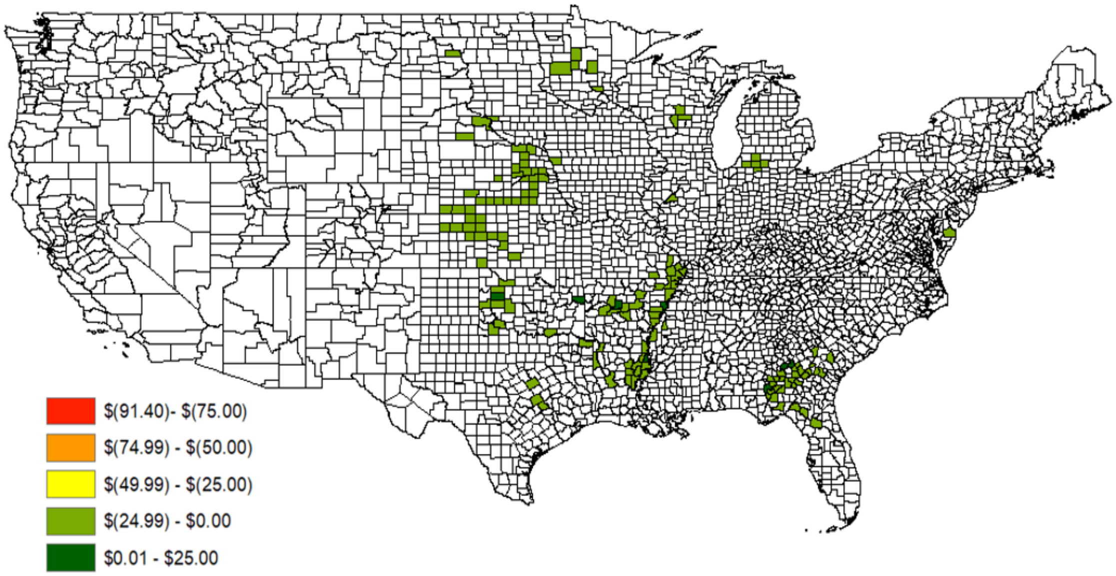

Figure 35. U.S. county map of $(PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\})$, non-irrigated soybeans

Soybeans are the crop for which the result of equation 39 yields the most counties where $PV[CE]_{Blend}$ exceeds $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$. Figure 35 is a county map of the results of equation 39 for non-irrigated soybeans. There is no geographic pattern in the counties that have a higher $PV[CE]_{Blend}$. Two counties in Oklahoma, a single county in Arkansas, and a cluster of counties on the Alabama/Georgia border have a $PV[CE]_{Blend}$ that exceeds $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$. In no county does the $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$ exceed $PV[CE]_{Blend}$ by more than \$25.00/acre.

Figure 36 is a county map of the results of equation 39 for non-irrigated seed cotton. Seed cotton is the crop in which the number of counties that $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$, exceeds $PV[CE]_{Blend}$by more than \$75.00/acre is greatest. Seed cotton production in Georgia overwhelmingly has a greater $PV[CE]_{PLC}$ than $PV[CE]_{Blend}$. For the majority of counties in the Texas Panhandle and south plains region of Texas, an area with extensive dryland cotton production, $PV[CE]_{PLC}$exceeds $PV[CE]_{Blend}$by more than \$25.00/acre. There is no county with non-irrigated seed cotton production for which $PV[CE]_{Blend}$ exceeds $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$.

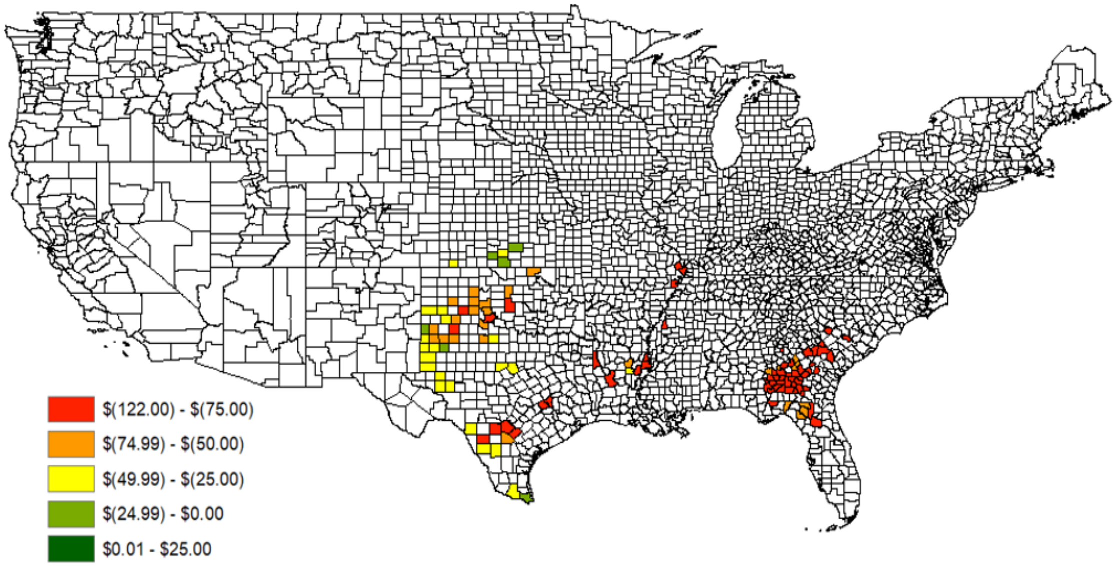

Figure 36. U.S. county map of $(PV[CE]_{Blend} - Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\})$, non-irrigated seed cotton

Figure 37 is a county map of the results of equation 39 for non-irrigated wheat. The geographic distribution of the results of equation 39 show more consistent patterns than the other seven commodities. The amount by which $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$, exceeds $PV[CE]_{Blend}$ for wheat is clustered by amount in the southeastern U.S., the Texas Panhandle and great plains region, and the pacific northwest. There is no county with non-irrigated wheat production for which $PV[CE]_{Blend}$ exceeds $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$.

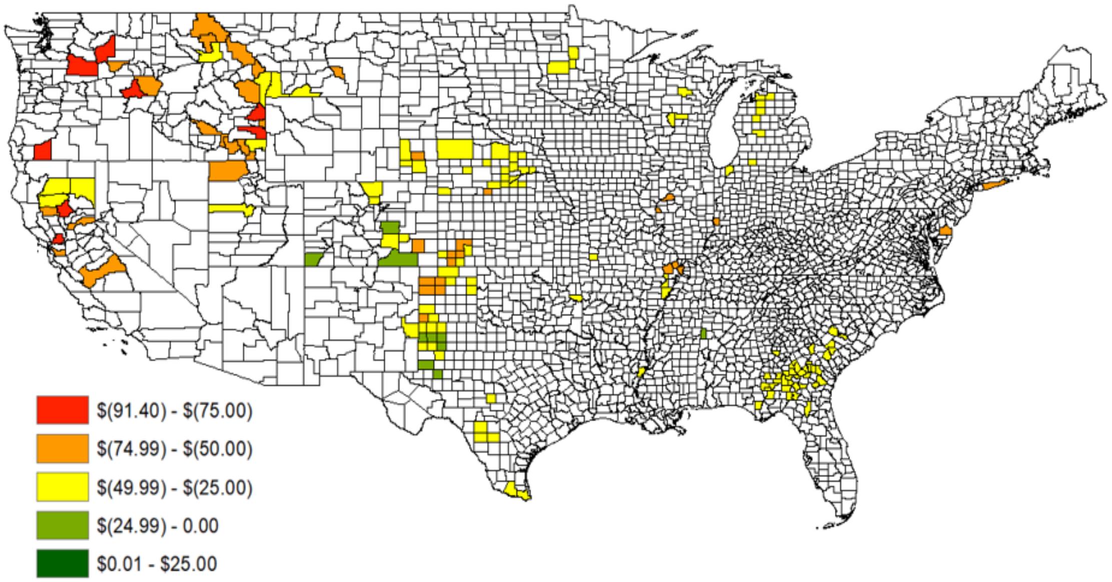

Figure 37. U.S. county map of ($PV[CE]_{Blend}$ - $Max\{PV[CE]_{ARC}, PV[CE]_{PLC}\}$), non-irrigated wheat

Conclusions

Commodity support programs are an integral part of the food production system in the United States. The 2014 farm bill provided options for producers that are likely to be extended under the 2018 farm bill with an option to reenroll in a program or change from ARC to PLC or vice versa. A plan for a blended program that allows enrollment of half of a farm's base acres in each program has been suggested as a method that could normalize payments.

A greater $PV[CE]$ indicates the need for a higher certain payoff in order for an economic agent to opt out of a situation with an uncertain outcome. Based on the $PV[CE]$ of revenue from production and the ARC, PLC, or the blend, producers are overwhelmingly likely to choose enrollment in PLC, whether or not the blend is available. The blended plan presented the highest $PV[CE]$ of revenue from production and a commodity program in only eight of 1,000 counties over eight program crops.

On average, the blended plan holds the most value for soybeans, in which eight counties have the highest $PV[CE]$ from enrollment in the blend. Based on current market conditions, the $PV[CE]_{PLC}$ shows that PLC is the program that will provide farmers with the most revenue. The difference in $Max\{PV[CE]_{PLC}, PV[CE]_{ARC}\}$, and $PV[CE]_{Blend}$ may not seem substantial when considering a single acre over a five year period, however when per acre value is multiplied by 100 or even 1,000 acres the difference can quickly become substantial.

The result of equation 39 for corn means that in most cases, producers would require a higher certain payment to defer enrollment in PLC than to defer enrollment in the blended plan. With corn accounting for 40.0% of base acres (Figure 28), Figure 31 shows that a substantial amount of U.S. crop producers would prefer enrollment in PLC over the blend.

The results of this study indicate that the blended plan will not be financially beneficial to farmers under the current market outlook. The blend could gain value in a more volatile market. If crop prices were to rapidly increase beyond the reference price shortly after the signing of a farm bill, enrollment in the blended plan would provide more support as ARC revenue benchmarks rose as a result of the rapid price increase, while PLC payments would likely not exist. In the event that prices remain low, the blend would still not provide producers with the level of support available through the PLC program.

Numerous extensions exist for this study. The next step in pursuing this research will be to incorporate irrigated cropland into a similar nationwide study. Testing different weights for the blended plan under the same functional form and expanding to different functional forms will also provide additional information in answering whether or not there is a need for a blended commodity support program.

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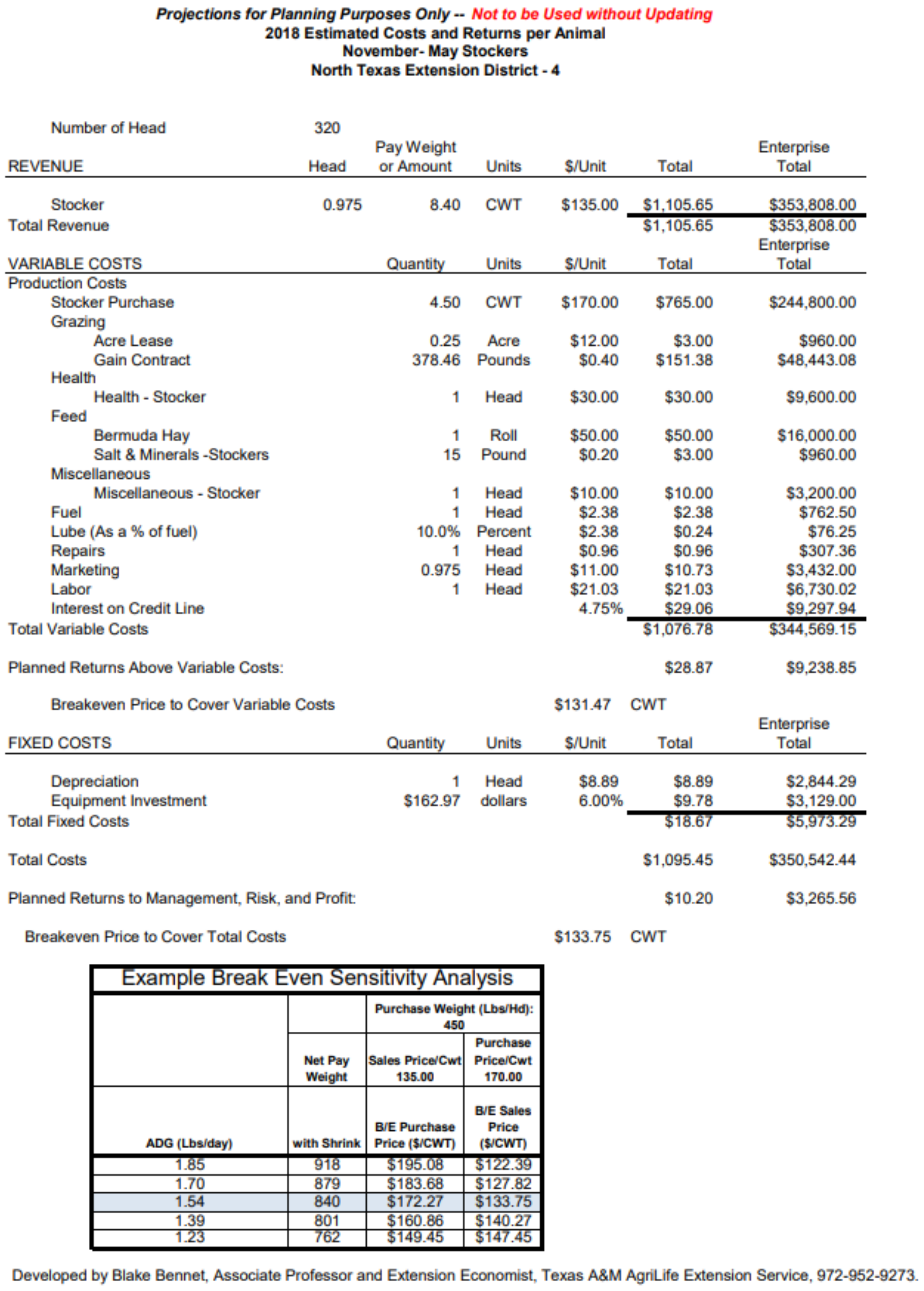
APPENDIX A.

TEXAS A&M AGRILIFE EXTENSION NOVEMBER – MAY STOCKER BUDGET; DISTRICT 4



Projections for Planning Purposes Only -- Not to be Used without Updating

2018 Estimated Costs and Returns per Animal

November- May Stockers

North Texas Extension District - 4

Number of Head 320

REVENUE	Head	Pay Weight or Amount	Units	$/Unit	Total	Enterprise Total
Stocker	0.975	8.40	CWT	$135.00	$1,105.65	$353,808.00
Total Revenue					$1,105.65	$353,808.00
VARIABLE COSTS		**Quantity**	**Units**	**$/Unit**	**Total**	**Enterprise Total**
Production Costs						
Stocker Purchase		4.50	CWT	$170.00	$765.00	$244,800.00
Grazing						
Acre Lease		0.25	Acre	$12.00	$3.00	$960.00
Gain Contract		378.46	Pounds	$0.40	$151.38	$48,443.08
Health						
Health - Stocker		1	Head	$30.00	$30.00	$9,600.00
Feed						
Bermuda Hay		1	Roll	$50.00	$50.00	$16,000.00
Salt & Minerals -Stockers		15	Pound	$0.20	$3.00	$960.00
Miscellaneous						
Miscellaneous - Stocker		1	Head	$10.00	$10.00	$3,200.00
Fuel		1	Head	$2.38	$2.38	$762.50
Lube (As a % of fuel)		10.0%	Percent	$2.38	$0.24	$76.25
Repairs		1	Head	$0.96	$0.96	$307.36
Marketing		0.975	Head	$11.00	$10.73	$3,432.00
Labor		1	Head	$21.03	$21.03	$6,730.02
Interest on Credit Line				4.75%	$29.06	$9,297.94
Total Variable Costs					$1,076.78	$344,569.15
Planned Returns Above Variable Costs:					$28.87	$9,238.85
Breakeven Price to Cover Variable Costs				$131.47	CWT	
FIXED COSTS		**Quantity**	**Units**	**$/Unit**	**Total**	**Enterprise Total**
Depreciation		1	Head	$8.89	$8.89	$2,844.29
Equipment Investment		$162.97	dollars	6.00%	$9.78	$3,129.00
Total Fixed Costs					$18.67	$5,973.29
Total Costs					$1,095.45	$350,542.44
Planned Returns to Management, Risk, and Profit:					$10.20	$3,265.56
Breakeven Price to Cover Total Costs				$133.75	CWT	

Example Break Even Sensitivity Analysis

		Purchase Weight (Lbs/Hd): 450	
	Net Pay Weight	Sales Price/Cwt 135.00	Purchase Price/Cwt 170.00
ADG (Lbs/day)	with Shrink	B/E Purchase Price ($/CWT)	B/E Sales Price ($/CWT)
1.85	918	$195.08	$122.39
1.70	879	$183.68	$127.82
1.54	840	$172.27	$133.75
1.39	801	$160.86	$140.27
1.23	762	$149.45	$147.45

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