ECONOMICS OF COVER CROPS, TILLAGE, AND COOL-SEASON GRAZING IN SOUTHERN GREAT PLAINS CATTLE OPERATIONS

By

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Title of Study: ECONOMICS OF COVER CROPS, TILLAGE, AND COOL-SEASON GRAZING IN SOUTHERN GREAT PLAINS CATTLE OPERATIONS

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Abstract: The first essay evaluates the usage of tillage and summer cover crops in stocker cattle operations. No-till establishment and cover crops are promoted to improve soil health and profitability. Data from a five year, completely randomized experiment are used in mixed-effects regression models to estimate the effects of tillage establishment method and the use of summer cover crops relative to a summer fallow. Enterprise budgeting was used to determine the relative net returns of the investigated systems. One-way analysis of variance models suggest that total bodyweight gain ha^{-1} was significantly higher in no-till established winter pastures with a summer fallow at the 95% confidence level. No-till and summer fallow paddocks realized lower machinery costs associated with pasture establishment, giving such a system an economic advantage. Additional revenues from grazable summer cover crops did not outweigh additional costs in seed, fuel, and chemical applications. Overall, no-till established winter wheat pasture with a subsequent summer fallow was the most economical system. The second essay evaluates grazing season extension in bermudagrass pastures through stockpiled bermudagrass, winter annual crops, and summer annual crops. Data from a four year, completely randomized experiment are used in a mixed effects regression analysis to estimate the effect of warm-season forage stockpiling and summer and winter annual forage crops on 205-day adjusted calf weaning weights and total kg of hay and cube supplement fed per month. Enterprise budgeting was used to model the experiment and find the most economical system. Calf birth weight, adjusted calf weaning weights, and cow body condition score prior to breeding did not differ between systems at the 95% confidence level. Total cubes fed per month was significantly higher in the conventional bermudagrass pasture with hay and cube supplement system, and hay fed per month was significantly higher in a bermudagrass pasture with bermudagrass stockpile and warm and cool-season annual cropland acres. Increased machinery costs, seed costs, and fertilization requirements associated with bermudagrass stockpiling and warm and cool-season annuals outweighed any feed cost savings. As a result, the conventional bermudagrass pasture with hay and cube supplement system produced the highest expected net returns.

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CHAPTER I

PROFITABILITY OF GRAZING NO-TILL ESTABLISHED WINTER WHEAT PASTURE AND SUMMER COVER CROPS ON SEMI-ARID CROPLAND ACRES

Abstract

No-till establishment (NT) and cover crops (CC) are two agricultural practices promoted to reduce externalities with clean-till (CT) and fallow practices, better soil health, and improve producer profitability. Some research reports economic value for NT on water-limited cropland acres, helping to advance farmer adoption; however, economic research associated with CC is limited. This study determines the economics of NT and CC for small grain pasture grazing systems in the Southern Great Plains (SGP). Data from a five-year, completely randomized design (CRD) grazing experiment were used in mixed-effects regression models to estimate the effects of establishment method (CT and NT) and either summer fallow (SF) or summer CC on average daily gain (ADG), steer grazing days (SGD), and total gain (TG) ha^{-1}. Enterprise budgeting was used to determine the relative net benefits of CTSF, NTSF, CTCC, and NTCC systems. Winter TG was the same for CTSF and NTSF systems; however, the NTSF realized 39 and 21 kg TG ha^{-1}

more ($P \leq 0.0001$) than the CTCC and NTCC systems, respectively. TG on CC was 11 kg ha^{-1} greater ($P \leq 0.0001$) for NT than CT. NT realized lower costs for machinery labor and fuel than CT, giving it an economic advantage; however, revenues from grazing CC did not outweigh the additional costs of seed, fuel, and chemical applications. Overall, the NTSF system produced \$34.04 ha^{-1} greater net returns than the next best system. This result was not sensitive to relative changes in prices of glyphosate, labor, fuel or cover crop seed.

Introduction

No-till (NT) establishment and cover crops (CC) pose multiple advantages to improving soil health and productivity. NT has been highly adopted among producers in the United States; however, CC are not used at comparable rates. The 2010 and 2011 Agriculture Resource Management Survey (ARMS) conducted by the Economic Research Service (ERS) showed that NT or strip tillage plantings composed 39% of total U.S. cropland in corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), soybeans (*Glycine max* L.), and wheat (*Triticum aestivium* L.) (Wade, et al., 2015). Relative to the nation, producers farming water-limited cropland acres in southern Nebraska, Kansas, western Oklahoma, eastern Colorado, eastern New Mexico, and central Texas had a 54% NT adoption rate. CC, on the other hand, have not been adopted at comparable rates as NT establishment techniques. In fact, only 4% of total U.S.A. respondents reported using CC on some portion of their fields, and only 0.3% of farmers had adopted CC on all their cropland acres. In 2014, adoption rates in the Southern Great Plains (SGP) were highly comparable to U.S. rates (Wade, et.al, 2015). CC have many agronomic and ecological benefits, including reduced erosion and improved soil water content (Bergtold, et al., 2019).

However, these benefits come with additional direct costs. These costs include seed and seed establishment, fertilizer, chemical, mechanical, and increased need of planning and management (Snapp et al., 2015). According to three separate farmer surveys conducted across over 40 states in the U.S.A., farmers suggested that direct costs, such as establishing and terminating CC, were a major deterrent to use (Dunn et al., 2016; Roesch-McNally et al., 2018; Plastina et al., 2018).

NT establishment technology has been shown to reduce soil erosion and compaction, and increases organic matter, beneficial microbial activity, water holding capacity, and other physical, chemical, and biological benefits (Derpsch et al., 2010). In addition, yields (grain and forage) obtained from NT establishment are comparable with yields obtained from CT establishment without environmental degradation (Grandy et al., 2006; Varner et al., 2010). NT establishment for grain and forage has shown to incur lower cost than CT establishment, primarily due to reductions in machinery labor, fuel, lube, repairs, and maintenance costs (Archer et al., 2008; Biermacher et al., 2009). When accounting for machinery capital costs however, Decker et al. (2009) found NT has a higher capital expense than CT. Using a machinery complement template developed by Kletke and Sestak (1991), Decker et al. found that CT was more productive and profitable when accounting for initial capital costs in eight of ten tested wheat production systems. The two production systems that were found to be more profitable in NT establishment were in forage-only grazing operations.

CC have been shown to improve soil water holding content, increase total N, decrease topsoil temperature, reduce erosion, compete with weeds for resources, and assist in hardiness of the following crop (Bergtold et.al, 2017; Ghimire et.al, 2019).

Blanco-Canqui et al. (2012) concluded that CC have yield increasing potential in cash crops according to a 15-year study in central Kansas. They concluded that increased soil organic carbon, higher N concentration, and soil water content were some of the sources of yield increases. Differing from the findings of Blanco-Canqui et al. (2012), Boyer et al. (2018) observed in a 29-year cotton and winter cover crop experiment in Tennessee that the highest net present value yields occurred when CC were not used. From this information, Boyer et al. concluded a risk-neutral producer achieved the highest net present value in a CT and no CC system. In grazing operations specifically, Horn et al. (2021) suggested short cycle drought resistant legume CC in Oklahoma could result in stocker cattle grazing profitability when managed appropriately. Horn et al. noted that while total yield was negatively affected by the addition of legume-based crops, the nutrient value of forage was enhanced.

There is some evidence that suggests NT establishment improves cattle performance on wheat pasture (Bowman et al., 2008). Beck et al. (2017) concluded that NTSF and NTCC systems produced higher average daily gain (ADG) and body weight (BW) gain relative to a CTSF system. However, these results were found in a region with an annual precipitation greater than 127 cm. More economic information is needed before recommendations can be made to farmers regarding whether or not they should adopt NT and summer CC on water-limited cropland acres in the SGP. The objectives of this study were to (i) to determine the effects that establishment method (CT and NT) and summer management (SF and CC) had on ADG, stocking rate (SR), steer grazing days (SGD), and total gain (TG) ha^{-1}, (ii) to determine the system that has the greatest expected net return to land, management and farm overhead, and (iii) to determine how sensitive the base-case results are to incremental changes in prices of herbicide, labor, fuel, and CC seed. We hypothesize that animal performance measures (i.e., ADG, SR, SGD, and TG) are not significantly different between establishment technique (CT and NT) and summer management (SF and CC) practice.

Materials and Methods

Experimental description

All animal procedures in the following study were performed under the recommendations of the Guide for Care and Use of Agricultural Animals and Research and Teaching and were approved by the Noble Research Institute's Animal Care and Use Committee (IACUC) prior to the initiation of the study in 2015.

Data were obtained from a grazing experiment conducted in south-central Oklahoma at the Noble Research Institute's Pasture Research and Demonstration Farm near the community of Ardmore, Oklahoma, U.S.A. (34°13'00.9"N, 97°12'31.1"W) on Chickasha loam (fine-loamy, mixed, active, thermic Udic Argiustolls) and Renfrow silt loam (fine, mixed, superactive, thermic Udertic Paleustolls) soils. Animal performance measures (ADG, SR, SGD, and TG) were collected from a split plot, completely randomized design experiment conducted across five production years (2015/16 - 2019/20). Ten 4.05 hectare (ha) experimental pastures were randomly assigned to either NT or CT establishment treatments, providing for 5 replications of each. Then, each of the 4.05 ha pastures were divided into 2.025 ha paddocks and randomly assigned to either the conventional summer management practice of SF or the alternative practice of establishing a mix of CC for grazing with stocker cattle. This resulted in five replications of four alternative stocker cattle grazing systems, namely: CT established winter small grain forage with a SF (CTSF), NT established winter small grain forage with a SF (NTSF), CT established winter small grain forage with a summer CC (CTCC), and NT established winter small grain forage with a summer CC (NTCC).

Agronomic practices

Winter small grain pasture establishment began in the early fall (September) of 2015-2019. Equal blanket applications of N in the form of urea (46-0-0) were applied to all ten paddocks from 2015-2019 for the winter cereal forage crop at an average rate of 168 kg ha^{-1} (77 kg N ha^{-1}). No fertilizer applications were made prior to summer cover crop plantings. According to soil test, diammonium phosphate (18-46-0) fertilizer was applied to all paddocks at a rate of 56 kg ha^{-1} (26 kg P ha^{-1}) in 2017. No potassium (K) was required during the course of the study. Lime (100% ECCE equivalent) was applied at a rate of 1121 kg ha^{-1} in 2017.

Chemical or mechanical preparation practices occurred before planting. Both primary and secondary tillage were utilized. Tillage practices included offset discing, tandem discing, and cultipacking prior to seed establishment. Chemicals used for burndown and termination included glyphosate (Ranger Pro, Monsanto, Creve Coeur, Missouri, U.S.A.) at a rate of 2.3 L ha^{-1} and 2,4-D, dicamba (Brash, WinField United, Arden Hills, Minnesota, U.S.A.) at a rate of 3.5 L ha^{-1}. The presence of fall armyworms (*Pseudaletia unipuncta* L.) in 2016/17 and 2017/18 required treatment with lambda-cyhalothrin based insecticide (Silencer, ADAMA, Aventura, Florida, U.S.A.) at a rate of 0.3 L ha^{-1}.

Planted cereal varieties varied over years, with Gallagher wheat (106.48 kg ha^{-1}) and Maton rye (*Secale cereale* L.) (28.02 kg ha^{-1}) in 2015. Gallagher wheat (134.50 kg ha^{-1}) in 2016, NF101 wheat (134.50 kg ha^{-1}) in 2017 and 2018, and NF201 triticale (×*Triticosecale* Wittmack) (134.50 kg ha^{-1}) in 2019. In 2015, imidacloprid based seed treatment (Rancona Crest, Chemtura AgroSolutions, Philadelphia, Pennsylvania, U.S.A.) was applied to the Gallagher wheat and Maton rye mix in all systems. The average planting date for winter pasture was September 22.

A CC mix of species was planted at 33.63 kg ha^{-1} on the CTCC and NTCC systems each year. These mixes included 6.73 kg ha^{-1} iron and clay cowpeas (*Vigna unguiculata* L.), 6.73 kg ha^{-1} soybeans (*Glycine Max* L.), 3.36 kg ha^{-1} sunn hemp (*Crotalaria juncea* L.), 3.36 kg ha^{-1} pearl millet (*Pennisetum glaucum* L.), 2.24 kg ha^{-1} German (foxtail) millet (*Panicum italicum* L.), 2.24 kg ha^{-1} browntop millet (*Urochloa ramosa* L.), 4.48 kg ha^{-1} brown midrib grazing corn, and 3.36 kg ha^{-1} buckwheat (*Fagopyrum esculentum* L.) in 2016 and 2017. In 2018 and 2019, the mix consisted of 6.73 kg ha^{-1} pearl millet, 3.36 kg ha^{-1} okra (*Abelmoschus esculentus* L.), and 23.54 kg ha^{-1} iron and clay cowpeas. The average planting date for summer CC was June 4, but planting dates were consistently earlier for NTCC paddocks. NTCC was planted 14 days earlier than CTCC in 2016, 39 days earlier in 2017, 26 days earlier in 2018, and 6 days earlier in 2019 all due to field conditions favoring NT. Rainfall data suggested above average rainfall throughout the experiment (Table 1.1).

Periods within growing season did have dry spans, which hindered crop growth. However, during periods requiring large amounts of field operations, high moisture conditions slowed tillage, planting, and spraying. Overall, the study period average rainfall was above the long-term average in all individual months of the study.

Winter pasture grazing management

Grazing initiation and termination protocol depended on available forage in dry matter (DM) per acre. Once plots reached 1569.19 kg DM ha^{-1}, cattle were grazed until forage reached a termination level of 1345.02 kg DM ha^{-1}. Forage biomass levels were monitored weekly post emergence using a monthly calibrated rising plate meter (Jennquip EC09 - Jennquip - Feilding, New Zealand) resulting from regression calibration equations developed for each treatment. These regression calibration equations were developed from 30 clipped measurements per treatment, representing the full range of forage mass available within the treatment (Cho, et al., 2019). Clippings from a 38.1-cm by 38.1-cm quadrant frame were collected and wet clipping weights in grams recorded. After drying in a forced air drier at 60℃ for 48 hours, clippings were weighed, and samples placed back into the dryer. This process was repeated until clipping weights stabilized. Timing of cattle placement, cattle removal, tillage, chemical applications, and hay harvesting activities are reported chronologically by system in Table 1.2.

Angus based (*bos taurus*) cattle with average beginning and ending weights ranging from 251.10$\pm$27.04 - 396.27$\pm$57.35 kg were grazed on the winter cereal pasture. All cattle were sourced from Noble Research Institute farms and local sale barns. All cattle were preconditioned at Noble Research Institute's Oswalt Road Ranch facility (33°59'23.9"N 97°15'15.9"W), stratified by weight, and sorted into assigned system groups. The preconditioning period included common veterinary practices and vaccinations within 24 hours of receiving the cattle. Following Beef Quality Assurance (BQA) protocols, cattle were vaccinated for bovine rhinotracheitis-virus (IBR) and diarrhea parainfluenza-respiratory syncytial virus (BRSV) (BoviShield Gold 5, Zoetis Inc., Kalamazoo, Michigan, U.S.A.) at a dosage of 2 mL injected subcutaneously in the neck according to BQA protocol, clostridium chauvoei-septicum-haemolyticum-novyi-sordellii-tetani-perfingens types C&D bacterin-toxoid (blackleg) (Calvary 9, Merck Animal Health, Madison, New Jersey, U.S.A.) in two 2 mL subcutaneous injections three weeks apart, and infections pododermatitis (foot rot) (Fusoguard, Elanco U.S. Inc., Farm Animal Business, Larchwood, Iowa, U.S.A.) in two 2 mL subcutaneous injections three weeks apart. Cattle were also given an intranasal inoculation against Mannheimia Haemolytical and Pasturella multocida bacterin (BRD) (Once PMH IN, Merck Animal Health, Madison, New Jersey, U.S.A) in a 2 mL dose. Additionally, all cattle were treated for horn flies, face flies, and biting and sucking lice with a pour-on insecticide at 8 mL per calf (Cylence, Bayer Animal Health, Shawnee, Kansas, U.S.A), dewormed (Valbazen drench with albendazole, Zoetis Inc., Kalamazoo, Michigan, U.S.A) in a 20 mL dosage, and tested for the presence of persistent infection of bovine viral diarrhea virus (BVD). Full (not shrunk) weights were averaged over two consecutive days at the beginning and end of the grazing period, with weights obtained every 28 days during grazing to calculate ADG (Watson et al., 2013). In 2015, 2016, and 2020 above average rainfall amounts resulted in lags in winter animal placement. In these three years, cattle did not begin grazing until mid-December with an average starting date of December 10th. However, due to below average rainfall conditions in 2017 and 2018, cattle could not be placed on pasture until mid-February, with an average starting date of February 14th. SR varied by year and were on average 2.24$\pm$0.45 hd ha^{-1}. If forage did not reach termination level by the beginning of May, all stockers were removed from the paddock by early May in order to establish the summer CC. Throughout the experiment, cattle did not graze the paddocks to termination level. All cattle within each system were removed at the same time each year.

The fall to winter period of 2017/2018 was excessively dry in comparison to other years of the study. In response to this drought, and above average cattle markets at the time, cattle that were purchased earlier in the fall were sold with the expectation that pasture would not be sufficient for grazing in this production year. However, timely rainfall in late February and early March resulted in significant pasture growth. In an effort not to omit the value of this unanticipated growth, the forage in each pasture was mowed, raked, and baled into 1.52 m x 1.83 m large round bales. The total DM weight in kilograms was recorded to later estimate kilograms of potential animal gain.

Summer cover crop grazing management

Stockers used for summer grazing were not retained from the winter period. A fresh set of stocker cattle were purchased from local sale barns and preconditioned at Noble Research Institute’s Oswalt Road Ranch facility under the same veterinary protocol as the winter stockers. Grazing initiation and termination protocol remained the same for the summer period. The process for measuring forage levels was also identical to the winter period.

Cattle began grazing in mid-July to early August, with average placement dates between July 19 and July 26. Average beginning and ending weights ranged from 319.11±42.79 – 354.79±44.26 kg. If forage did not reach the termination level by September, all stockers were removed from the paddock by early September to accommodate winter pasture establishment. As was the case with winter grazing, cattle did not graze to the termination level, and were all removed at the same time within each system. SR on CC varied by year and on average were 2.30±0.23 hd ha^{-1}.

<u>Economic methods</u>

Enterprise budgeting techniques were used to calculate expected benefits and costs for each of the four production systems (AAEA, 2000). Revenues were calculated for each system by multiplying the average VOG times the average TG ha^{-1} for each system, grazing period, and replication. Following Biermacher et al., 2017, VOG was calculated as

$$VOG_i = \left(\frac{EndPr_i \times EndWt_i - BegPr_i \times BegWt_i}{Gain_i}\right) \qquad (1)$$

where VOG_i is the total value of one kilogram of gain for an individual steer, i, $EndPr_i$ is the price ($ kg^{-1}) at the ending date, $EndWt_i$ is the average total body weight (kg) at the end of the period, $BegPr_i$ is the price ($ kg^{-1}) at the beginning date, $BegWt_i$ is the average total body weight (kg) at the beginning of the period, and $Gain_i$ is the total body weight gain for an individual steer throughout the experiment.

Average cattle prices were taken from ten years (2011-2020) of OKC National Stockyards medium to large number one steers price data (USDA, 2020). Sale prices for raised cattle were linearly interpolated using a price slide to better represent decreases in received price for higher bodyweight (BW) cattle, and as such, declining VOG. As price by weight differs by season, both the summer and winter period had individually calculated price slides associated with increased weight. The winter period price slide was \$-0.002 kg^{-1} kg^{-1} and the summer period price slide was \$-0.002 kg^{-1} kg^{-1}.

Cost accounting for each of the systems began once grazing was initiated in each period of each year. All input prices were obtained from local supply dealers in September of 2020 (Table 1.3). Custom rates were used for tillage and application costs (Sahs, 2020). Custom rates were further broken down into machinery, fuel, and labor costs using known percentages based upon tillage type. In NT, 14% of the total custom rate was labor, 46% was fuel, and 40% was fixed machinery expenses. In CT, 19% of the total custom rate was labor, 49% was fuel, and 32% was fixed machinery expenses. Chemical products were considered under the brand name purchased in the experiment. An annual interest rate of 5.5 percent was used to calculate the cost of operating capital for each enterprise, and to calculate the cost of interest for owning stocker cattle during the grazing period for each system.

The forage produced in the 2018/2019 winter period that was not grazed was harvested as hay and was converted to kilograms of beef using a ten kilograms of forage DM per one kilogram of beef conversion (Epplin et al., 2000). The converted hay was then multiplied by the winter period VOG to place a value on the excess forage.

Sensitivity analyses was conducted to determine how robust the base-case results are to relative incremental changes in the price of glyphosate, fuel, machinery labor, and cover crop seed. Break-even (BE) input price to the economically optimal system was found with each of the tested inputs.

Statistical analysis

Statistical analysis on the data was performed using the SAS software system (version 9.4) (SAS Institute, 2012). The effects of establishment treatment (CT and NT) and summer management practice (SF and CC) on measures of animal performance (i.e., beginning weights, ending weights, ADG, grazing duration, SR, SGD, and TG) were analyzed using one-way analysis of variance (ANOVA) using the Mixed Procedure in SAS (Littell et al., 1996). Differences of least squares by treatment system were compared using the pdmix800 macro installed program of SAS (Saxton, 1998). The model used for estimation is

$$y_{spt} = \gamma_s + \tau_{pt} + \varepsilon_{spt} \qquad (2)$$

where y_{spt} represents the response variable for system, *s*, period, *p*, and year, *t*, for each of the animal performance measures (i.e., beginning weight, ending weight, ADG, grazing duration, SGD, SR, and TG); γ_s is a treatment (system) fixed effect where $s \in \{\text{CTSF}, \text{NTSF}, \text{CTCC}, \text{NTCC}\}$; τ_{pt} is a period x year random effect where $\tau_{pt} \sim N(0, \sigma_\tau^2)$; and ε_{spt} is the error term where $\varepsilon_{spt} \sim N(0, \sigma_\varepsilon^2)$.

For the TG model, the potential for a split-plot random effect was evaluated using a likelihood ratio (LR) test. However, the estimated value of this random effect was not significant and, therefore, not included. Also, the number of cattle grazing each individual paddock (i.e., SR) was heterogeneous depending upon year. Because each individual animal has a unique and random response to grazing, the variability associated with aggregated TG within pastures differed, resulting in heteroskedastic error variances (Richter & Brorsen, 2006). In this case, the error term is described as $\varepsilon_{spt} \sim N(0, SR_{spt}^2 \sigma_\varepsilon^2)$, where SR_{spt}^2 is the number of cattle grazing each paddock in system s, period p, and year t. This was corrected by using estimated generalized least squares (EGLS). The corrected error variance resulted in new predicted values for TG ha^{-1}.

Results and Discussion

Animal performance

Least squares means for measures of animal performance (grazing initiation and termination weights and dates, ADG, grazing duration, SR, SGD, and TG) are reported for each period and production system in Table 1.4. During the winter period, grazing initiation weights (or dates) did not differ (P = 0.9300) between systems, indicating that animal performance measures on winter pastures were obtained under similar grazing initiation conditions. At the end of grazing during the winter period, the grazing termination weight did not differ (P = 0.0595) between the NTCC, NTSF, and CTSF systems, respectively, but cattle grazing the NTSF system did realize a 13.49 kg ha^{-1} advantage over the CTCC system. During winter grazing, ADG for the CTCC system was 0.14, 0.11, and 0.08 kg lower (P ≤ 0.0001) than the NTSF, CTSF and NTCC systems, respectively. Also, during the winter period, the average grazing duration for each system was the same with a mean grazing initiation date of 10-December and grazing termination date of 17-April; however, SR between systems did differ ($P \leq 0.001$) favoring CTSF and NTSF systems, both having pastures with forage levels able to support 0.09 head ha^{-1} more than the CTCC and NTCC, respectively. Overall, during the winter grazing period, the NTSF had the greatest ($P \leq 0.0001$) TG of 316 kg ha^{-1}, which was not statistically different than the 306.05 kg ha^{-1} produced by the CTSF system, but was 38.65 and 20.49 kg ha^{-1} greater than the CTCC and NTCC systems, respectively.

During the summer CC grazing period, grazing initiation weights differed ($P = 0.0019$) between the CTCC and NTCC systems with weights of CTCC cattle being 10.29 kg $head^{-1}$ heavier than NTCC cattle. This difference was due to pastures associated with the NTCC system meeting the forage-to-BW target minimum seven days earlier than the CTCC system, and cattle were lighter when stocked than cattle placed on pasture for the CTCC system one week later. Likewise, summer grazing termination weights were 7.85 kg $head^{-1}$ greater ($P = 0.0402$) in the CTCC system compared to the NTCC system. On average, during the summer grazing period, the grazing duration favored the NTCC system by 3 days compared to the CTCC system. ADG on CC was 0.11 kg greater ($P = 0.0404$) in the NTCC system compared to the CTCC system. Further, ADG was numerically higher in the winter period compared to grazing CC in the summer, suggesting that grazing cereal pasture offered a more efficient gain per head per day compared to summer cover crops ($P \leq 0.05$). Time lags associated with the termination of cover crops to grazing could explain some of this relative difference. In the summer period, the NTCC system realized 4.19 more ($P \leq 0.0001$) SGD compared with the

CTCC system. This was due to the NTCC system having 3 extra days of grazing and a 0.10 greater SR compared to the CTCC system. Overall, during the summer grazing period, the NTCC system produced 11.23 more (P = 0.0087) TG ha^{-1} than the CTCC system.

When summed over winter and summer grazing periods, cattle in the CTCC and NTCC systems realized 45.19 and 64.65 more TG ha^{-1} then cattle grazing the CTSF and NTSF winter grazing systems, respectively. Consistent with findings of Beck et al. (2017), the NTSF and NTCC systems had consistently higher gains relative to the CTSF and CTCC systems.

<u>Economics</u>

Average per hectare sources of revenues, production costs, and net returns for each system are also reported in Table 1.5. Due to the price slide for heavier weight cattle, VOG varied between systems. In the winter period, the highest average VOG was in the CTCC system, at \$2.15 kg^{-1} gain, and the lowest VOG was observed in the NTSF system, at \$1.96 kg^{-1} gain. The average winter VOG was \$2.06 kg^{-1}. Summer VOG was lower than winter, with CTCC receiving \$1.21 kg^{-1} gain and NTCC receiving \$1.71 kg^{-1} gain. Revenues from grazing and hay production summed across grazing period (winter and summer) for the NTCC system was \$814 ha^{-1} (\$668 ha^{-1} for winter plus 146 ha^{-1} for summer), which is \$145.89 ha^{-1} (winter only), \$103.11 ha^{-1} (winter only), and \$64.42 ha^{-1} (\$7.69 ha^{-1} for winter, \$56.73 ha^{-1} for summer) ha^{-1} more than the CTSF, NTSF, and CTCC systems, respectively.

In terms of gross revenue, the NTCC system has an economic advantage; however, it is important to understand the costs associated with each system, most importantly the costs that vary between systems. For this analysis, the costs that vary between systems are those associated with the glyphosate burndown, the CC seed, machinery labor, machinery fuel and maintenance, machinery fixed ownership costs, baling hay, interest on operating capital, and interest on steer ownership.

On average, NTSF and NTCC systems required \$31 ha^{-1} for glyphosate for an initial burndown for winter pasture while CTSF and CTCC systems did not. In addition, the NTCC had an additional \$15 ha^{-1} glyphosate application cost after winter grazing to chemically burndown wheat stubble and broadleaf weeds. While all systems incurred a 74 ha^{-1} cost of seed for winter pasture establishment, NTCC and CTCC incurred an additional 74 ha^{-1} seed cost for cover crop establishment.

The three machinery costs of interest include (1) labor, (2) fuel and maintenance, and (3) annual fixed ownership costs. NT and SF were consistently more cost effective than CT and CC. In the winter period, NT machinery costs did not differ between NTCC and NTSF; however, CTCC required additional tillage relative to CTSF to terminate the cover crops. This resulted in \$6 ha^{-1} higher cost of labor, \$16 ha^{-1} higher cost for fuel and maintenance, and \$10 ha^{-1} higher fixed ownership cost. In the summer period, CTCC was 17 ha^{-1}, \$35 ha^{-1}, and \$14 ha^{-1} higher than NTCC for labor, fuel and maintenance, and fixed ownership costs, respectively. This aligns with findings by Archer, et al. (2008) and Biermacher, et al. (2009), as increased machinery costs outweigh the chemical savings associated with CT.

As a result of the increased cost of tillage, total cost was highest in CT operations, regardless of period. The increased seed, machinery, and labor costs associated with CC outweighed the benefits associated with the extra grazing period. Total cost was highest in CTCC realizing \$773 ha^{-1}. This is \$107 ha^{-1} higher than NTCC (\$55 ha^{-1} in the winter and \$52 ha^{-1} higher in the summer), \$286 ha^{-1} higher than CTSF (winter only), and \$297 ha^{-1} higher than NTSF (winter only).

Average net returns for each system were \$235.47 ha^{-1} for NTSF, \$201.43 ha^{-1} for CTSF, \$168.48 ha^{-1} for NTCC, and \$-23.00 ha^{-1} for CTCC respectively. Increased costs associated with tillage practices and cover crop establishment were the chief source of differences in net returns. While CT practices had slightly higher VOG per kg of BW gain, NT practices on average produced more total gain per hectare, resulting in higher gross revenues when compared to CT counterparts with the same summer practices (SF or CC). When compared to NTSF (most economical system) net returns were \$34, \$67, and \$258 ha^{-1} lower for the CTSF, NTCC, and CTCC systems, respectively.

Differences in net returns from incremental *ceteris paribus* changes in prices of glyphosate, fuel, labor, and cover crop seed are reported in Table 1.6. Base-case prices were increased and decreased in increments of +30%, -30%, and -50% of the original base-case price. For glyphosate, CT systems were unaffected by price changes, as they used no glyphosate. NTSF remained the preferred system regardless of the price of glyphosate analyzed. Additional investigation revealed the base-case price of glyphosate would have to increase by 105% (\$13.54 L^{-1}) in order for the NTSF and CTSF systems to break-even with each other.

Fuel usage was highest in CT and CC systems, making them most sensitive to changes in price. Reducing the price of diesel by 30% (from \$0.66 L^{-1} to \$0.46 L^{-1}) resulted in \$25.69 ha^{-1} higher net return in NTSF relative to CTSF. While this was lower than the base-case net return difference of \$34.04 ha^{-1}, NT was still more economical than CT. Even when diesel price was reduced to \$0 L^{-1}, NTSF remained the optimal system economically. Increases in fuel prices consistently made NT and SF more feasible, resulting in no change from NTSF as the highest returning system.

A 30% reduction in the wage rate (from \$15 to \$10.50 hr^{-1}), the CTSF system realized a net return \$29 ha^{-1} less than NTSF. In fact, for a wage rate equal to \$0 hr^{-1}, the NTSF system was still preferred compared to all other systems. As CT and CC systems require more total labor, increases in the wage rate increased the economic advantage of NT and SF relative to CT and CC systems.

Incremental changes in cover crop seed revealed that none of the tested price reductions or increases caused derivation from NTSF as the preferred system. As the higher net return CC system, NTCC was still \$62 ha^{-1} lower in net returns when compared to the lower net return SF system, CTSF. NTCC reached BE with NTSF when cover crop seed price was decreased by 86%, or at a per unit price of \$0.31 kg^{-1} of cover crop seed mix. Overall, our sensitivity analysis suggests that the base-case results are very robust and not sensitive to the prices associated with the costs that vary between systems.

Conclusions

The goal of this study was to determine the economic net returns for winter pasture grazing systems that utilize conservation tillage establishment and summer cover crops practices compared to the conventional clean tillage and summer fallow practices common to the Southern Great Plains. Overall, the findings suggest the economic net returns were greatest for the system that established winter pasture using no-till planting and a summer fallow. Further, the cost of planting and grazing summer cover crops using conventional and conservation establishment practices were greater than the benefits associated with producing weight gain on stocker cattle. Moreover, the results of a sensitivity analysis revealed that net returns for each system analyzed were not sensitive to incremental changes in the prices of inputs for the costs that varied between systems. From a policy standpoint, climate smart subsidies or cost sharing programs for grazable cover crops could assist in making them feasible to the average producer. Further research focused on the production and economics of alternative summer cover crop grazing systems is warranted.

Table 1.1. Rainfall in centimeters by month and year at the Pasture Research and Demonstration Farm located near Ardmore, Oklahoma.

Month/Year	2015	2016	2017	2018	2019	2020	Avg.	30-yr avg.
January	6.10	1.65	8.41	0.38	5.87	8.86	5.21	4.19
February	2.57	4.14	6.50	18.19	6.50	9.47	7.90	5.31
March	7.90	8.92	2.79	8.76	6.12	13.69	8.03	6.71
April	12.14	20.98	7.70	5.1 1	15.11	6.45	11.25	8.38
May	48.41	13.44	13.72	15.34	11.48	-	20.48	14.10
June	38.28	9.47	5.92	6.81	13.72	-	14.84	10.69
July	14.61	2.24	13.51	5.16	1.47	-	7.40	7.16
August	1.04	5.03	17.50	13.89	15.72	-	10.64	6.99
September	4.24	6.20	5.23	23.14	10.41	-	9.84	8.08
October	19.86	4.04	2.59	32.26	13.61	-	14.47	10.90
November	20.62	5.38	0.15	1.35	7.54	-	7.01	5.69
December	15.95	2.08	4.60	13.13	2.08	-	7.57	5.79
Total	191.72	83.57	88.62	143.52	109.63	38.47	124.63	93.99

Source: www.mesonet.org

Table 1.2. Chronology of production activities by production system.

		Production system[a]			
Production activity:	Month	CTSF	NTSF	CTCC	NTCC
Apply glyphosate and dicamba plus 2,4-D as a chemical burndown	Aug		x		x
Apply lime at 100% ECCE (every third year)	Sep	x	x	x	x
Offset discing		x		x	
Tandem discing		x		x	
Field cultivation		x		x	
Plant small grain seed with conventional drill		x		x	
Plant small grain seed with no-till drill			x		x
Apply N, P205, K20 fertilizers		x	x	x	x
Apply Lambda-cyhalothrin to control armyworm (every other year)	Oct	x	x	x	x
Purchase and precondition stocker steers		x	x	x	x
Place stocker cattle on winter pasture	Dec	x	x	x	x
Terminate grazing small grain pasture	Apr	x	x	x	x
Apply glyphosate plus dicamba as a chemical burndown					
Purchase and precondition stocker steers	May			x	x
Offset discing		x		x	
Field cultivation				x	
Plant cover crop with conventional drill	June			x	
Plant cover crop with no-till drill					x
Place stocker cattle on cover crop mixture	Jul			x	x
Terminate grazing of cover crop mixture	Aug			x	x

[a] CTSF is clean-till establishment of small grain pasture followed by summer fallow; NTSF is no-till establishment of small grain pasture followed by summer fallow; CTCC is clean-till establishment of small grain pasture followed by a cover crop pasture; and NTCC is no-till establishment of small grain pasture followed by a cover crop pasture.

Table 1.3. Prices and custom rates for operating inputs.

Operating input	Unit	Price
N	$ kg^{-1}	0.79
P2O5	$ kg^{-1}	0.84
Lime (100% ECCE)	$ MT^{-1}	44.09
Glyphosate (Ranger Pro)	$ L^{-1}	6.60
2,4-D plus Dicamba	$ L^{-1}	14.79
Lambda-Cyhalothrin (Silencer)	$ L^{-1}	9.25
Wheat seed	$ kg^{-1}	0.55
Cover crop seed mixture	$ kg^{-1}	2.20
Custom fertilizer application	$ ha^{-1}	19.32
Custom herbicide application	$ ha^{-1}	18.78
Custom tandem discing	$ ha^{-1}	32.22
Custom offset discing	$ ha^{-1}	31.78
Custom field cultivation	$ ha^{-1}	29.65
Custom no-till drilling	$ ha^{-1}	46.95
Custom clean-till drilling	$ ha^{-1}	37.88
Custom cutting, raking, and baling hay (1.52 m x 1.83 m)	$ bale^{-1}	22.34
Custom mowing residual cover crop	$ ha^{-1}	36.28

Table 1.4. Mean and standard error of the mean values for grazing initiation and termination dates and weights, and stocking rates and least squares means for average daily gain, steer grazing days, and total gain by grazing period and production system.

	Production System[a]								
	CTSF		NTSF		CTCC		NTCC		
Animal performance measure:	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.	P-value
Winter period									
Grazing initiation date (mm/dd)	01/05	-	01/05	-	01/05	-	01/05	-	-
Grazing initiation weight (kg)	250.59	3.73	251.90	3.71	249.68	3.80	249.85	3.75	0.9300
Grazing termination date (mm/dd)	04/18	-	04/17	-	04/17	-	04/16	-	-
Grazing termination weight (kg)	386.44AB[b]	23.88	390.17A	23.88	376.68B	23.90	384.48AB	23.88	0.0595
Average daily gain (kg day^{-1})	1.14AB	0.13	1.17A	0.13	1.03C	0.13	1.11B	0.13	0.0001
Grazing duration (days)	103.38A	17.33	102.39B	17.33	102.43B	17.33	100.96C	17.33	0.0001
Steer grazing days (head days)	235.32A	42.82	253.01A	42.82	253.11B	42.82	251.95B	42.82	0.0001
Stocking rate (hd ha^{-1})	2.14A	0.25	2.17A	0.25	2.05B	0.25	2.08B	0.25	0.0001
Total gain (kg ha^{-1})	306.05AB	73.91	316.05A	73.90	277.40C	73.92	295.56B	73.91	0.0001
Summer period									
Grazing initiation date (mm/dd)	-		-		07/26	-	07/19	-	-
Grazing initiation weight (kg)	-		-		319.05	22.93	308.76	22.85	0.0019
Grazing termination date (mm/dd)	-		-		09/01	-	08/26	-	-
Grazing termination weight (kg)	-		-		353.03	23.81	345.18	23.69	0.0402
Average daily gain (kg day^{-1})	-		-		0.85	0.12	0.96	0.12	0.0404
Grazing duration (days)	-		-		35.18	3.77	38.12	3.76	0.0001
Steer grazing days (head days)	-		-		77.96	5.51	88.32	5.49	0.0001
Stocking rate (hd ha^{-1})	-		-		2.24	0.11	2.35	0.11	0.0001
Total gain (kg ha^{-1})	-		-		73.75	8.39	85.14	7.93	0.0087

[a] CTSF is clean-till establishment of small grain pasture followed by summer fallow; NTSF is no-till establishment of small grain pasture followed by summer fallow; CTCC is clean-till establishment of small grain pasture followed by a cover crop pasture; and NTCC is no-till establishment of small grain pasture followed by a cover crop pasture.

[b] Numbers in the same row of the same section with the same capital letter are not significantly different at the $P \leq 0.05$ significance level.

[c] Due to excess rainfall, cattle only grazed CTCC system in 2016, 2017, and 2018

Table 1.5. Total gain, sources of revenues, production costs and net returns to land, management and farm overhead by grazing period and production system.

	Production system[a]							
	CTSF		NTSF		CTCC		NTCC	
Animal performance and economic variables:	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Sources of revenue								
Total gain from grazing (kg ha^{-1})	306.05	-	316.05	-	277.42	73.82	295.57	85.13
Total gain from baled hay (kg ha^{-1})	33.37	-	46.90	-	29.26	-	31.08	-
Average value of gain (\$ kg^{-1})	2.03	-	1.96	-	2.15	1.21	2.11	1.71
Gross revenue from grazing (\$ ha^{-1})	620.62	-	619.18	-	597.56	89.16	622.79	145.89
Gross revenue from hay production (\$ ha^{-1})	67.66	-	91.88	-	63.03	-	65.49	-
Total gross revenue (\$ ha^{-1})	668.28	-	711.06	-	660.59	89.16	668.28	145.89
Production costs								
Glyphosate for chemical burndown (\$ ha^{-1})	-	-	30.89	-	-	-	30.89	15.44
Dicamba plus 2,4-D for chemical burndown (\$ ha^{-1})	51.89	-	51.89	-	51.89	-	51.89	-
Lambda-cyhalothrin to control armyworm (\$ ha^{-1})	2.32	-	2.32	-	2.32	-	2.32	-
Small grain seed (\$ ha^{-1})	74.13	-	74.13	-	74.13		74.13	
Cover crop seed mix (\$ ha^{-1})	-	-	-	-	-	74.13	-	74.13
Fertilizers: N, P205, K20, and Lime (\$ ha^{-1})	127.84	-	127.84	-	127.84	-	127.84	-
Machinery labor for tillage, planting, fertilizer, and pesticide application (\$ ha^{-1})	30.09	-	15.59	-	36.13	28.66	15.59	11.91
Machinery fuel and maintenance for tillage, planting, fertilizer, and pesticide applications (\$ ha^{-1})	77.60	-	51.22	-	93.17	73.92	51.22	39.12

Machinery fixed ownership costs for tillage, planting, fertilizer, and pesticide applications ($ ha^{-1})	50.68	-	44.54	-	60.85	48.27	44.54	34.02
Cut, rake and bale hay into large round bales ($ ha^{-1})	13.69	-	19.25	-	16.82	-	12.76	-
Interest on operating capital ($ ha^{-1})	20.77	-	20.52	-	22.13	9.27	20.16	7.73
Interest on purchased stocker cattle ($ ha^{-1})	37.85	-	37.42	-	38.20	14.57	37.04	14.96
Total cost ($ ha^{-1})	486.85	-	475.60	-	523.47	249.28	468.37	197.32
Net return by period ($ ha^{-1})	201.43	-	235.47	-	137.12	-160.12	219.91	-51.43
Net return by system ($ ha^{-1})	201.43		235.47		-23.00		168.48	
Relative difference in net returns against best practice ($ ha^{-1})	-34.04		0.00		-258.47		-66.99	

[a] CTSF is clean-till establishment of small grain pasture followed by summer fallow; NTSF is no-till establishment of small grain pasture followed by summer fallow; CTCC is clean-till establishment of small grain pasture followed by a cover crop pasture; and NTCC is no-till establishment of small grain pasture followed by a cover crop pasture.

Table 1.6. Expected net returns ($ ha^{-1}) for alternative *ceteris paribus* changes in prices for glyphosate, machinery labor, machinery fuel, and cover crop seed mix by production system.

			Production system[a]			
Production input	Price scenario	Price	CTSF	NTSF	CTCC	NTCC
Price of glyphosate ($ L^{-1})	Base-case	6.60	201.43	235.47	-23.00	168.48
	Base-case - 30%	4.62	201.43	245.25	-23.00	183.14
	Base-case + 30%	8.59	201.43	225.69	-23.00	153.81
	Base-case + 50%	9.91	201.43	219.18	-23.00	144.04
Price of Diesel ($ L^{-1})	Base-case	0.66	201.43	235.47	-23.00	168.48
	Base-case - 30%	0.46	225.99	251.68	29.88	197.07
	Base-case + 30%	0.86	176.87	219.26	-75.89	139.87
	Base-case + 50%	0.99	160.50	208.45	-111.14	120.82
Price of labor ($ hr^{-1})	Base-case	15.00	201.43	235.47	-23.00	168.48
	Base-case - 30%	10.50	210.95	240.40	-2.49	177.16
	Base-case + 30%	19.50	191.91	230.54	-43.50	159.78
	Base-case + 50%	22.50	185.56	227.25	-57.18	153.98
Price of cover crop seed mix ($ kg^{-1})	Base-case	2.20	201.43	235.47	-23.00	168.48
	Base-case - 30%	1.54	201.43	235.47	0.46	191.94
	Base-case + 30%	2.87	201.43	235.47	-46.46	145.01
	Base-case + 50%	3.31	201.43	235.47	-62.11	129.37

[a] CTSF is clean-till establishment of small grain pasture followed by summer fallow; NTSF is no-till establishment of small grain pasture followed by summer fallow; CTCC is clean-till establishment of small grain pasture followed by a cover crop pasture; and NTCC is no-till establishment of small grain pasture followed by a cover crop pasture.

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CHAPTER II

PROFITABILITY OF BERMUDAGRASS STOCKPILING AND PLANTED ANNUAL PASTURE IN COW-CALF OPERATIONS

Abstract

Bermudagrass (*Cynodon dactylon* L.) stockpiling and seeded cool-season pastures can extend grazing seasons in cow-calf operations and reduce winter feeding costs, but less is known about how these practices interact and their effect on producer profitability. Data from a completely randomized-design experiment in South-Central Oklahoma were collected on three grazing treatments: bermudagrass pasture with hay and protein cube supplement (CONTROL), bermudagrass with stockpile and interseeded cool-season pasture (SPINT), and bermudagrass with stockpile and cropland warm and cool season annuals (SPCROP). A mixed effects analysis of variance model was used to estimate the effects of grazing treatment on 205-day adjusted weaning weights (AWT), total hay, and total cubes fed in each system. Enterprise budgeting was used to calculate the expected net return of each system. AWT did not vary between systems ($P = 0.8694$), resulting in similar revenues. Relative to other treatments, cubes fed were significantly higher in the CONTROL system ($P < 0.0001$) and hay fed was significantly higher in the SPCROP system ($P = 0.0036$). Increased machinery costs, seed costs, and fertilization

requirements in bermudagrass stockpiling, interseeding, and cropland production outweighed the cost savings associated with less feeding. As a result, the CONTROL system was most profitable, producing \$16 ha^{-1} and \$110 ha^{-1} higher net returns than the SPINT and SPCROP systems, respectively.

Introduction

Cow-calf operations in the Southern Great Plains (SGP) commonly graze bermudagrass (*Cynodon dactylon* L.) pastures and supplement cows with hay and protein cubes in the winter. Winter feeding costs account for the majority of expenses in cow-calf operations (Hibbard et al., 2021; Lardy and Caton, 2010; Lomas et al., 2000; Karn et al., 2005). Warm-season grass stockpiling, grazing annual summer and winter crops, and interseeding cool-season annual grasses into perennial pasture have been promoted as ways to extend grazing seasons and reduce feeding costs (Gunter et al., 2005; Troxel et al., 2014; Utley and McCormick, 1978). Of the five strategies to maintain animal performance while decreasing costs suggested by Benson (2010), grazing season extension attempts to meet two of these requirements by reducing the need for stored and purchased feedstuffs and decreasing forage harvesting and feeding machinery and labor costs. This study investigates the economics of grazing season extension through bermudagrass stockpiling and warm and cool-season forages in cow-calf operations of the SGP.

As a cool season annual, winter wheat (*Triticum aestivium* L.) can reduce winter feeding costs by extending the grazing season (Dillard et al., 2018; Mullenix & Rouquette, 2017). Cool-season grasses alone have been observed to increase the grazing season by up to 90 total days (Hoveland et al., 1978; Mullenix & Rouquette, 2017; Rouquette 2017). Wheat planted in mid-September typically increases in overall forage mass to an initial peak in late November, declines to a local minimum in late January, and then reaches its highest point early-to mid-May, a few weeks before senescence (Rouquette, 2015). Grazing winter wheat can reduce the need for both supplementary forage and protein cubes during the winter and spring. Dillard et al. (2018) found cool-season annual pastures increased cattle gain and soil cover (thus reducing erosion). A multi-year grazing experiment at Oklahoma State University in the early 1990s concluded that fall calving cows grazing wheat pasture on alternate days and calves with continuous calf creep access to wheat pasture increased calf gains and decreased the need of additional supplementation to the cows (Apple et al., 1991; Apple et al., 1993).

Summer annual cover crops (CC) are typically lower in forage quality than cool-season annual grasses. This is due to their comparatively lower leaf to stem ratios and total digestible nutrients (TDN) (Cowan and Lowe, 1998). Plants commonly used as CC, such as cowpeas (*Vigna unguiculata* L.), are a highly nutritive forage relative to warm-season perennial grasses (Caddel & Ennis, 2017). Warm-season forage legumes can decrease fertilization costs through nitrogen fixing Rhizobium-legume symbiosis (Brink and Fairborther, 1998) and pesticide costs through decreased weed and disease populations (SARE, 2012).

Warm-season perennial grasses enter winter dormancy at the first killing frost. In the Southern Great Plains (SGP), this is typically around mid-November. Stockpiling forage is the act of deferring grazing and allowing warm-season forage to reach maximum biomass levels. Stockpiling forage has been shown to reduce winter feed costs

(Beck et al., 2016; Hitz & Russell, 1998; Johnson et al., 2002; Rieserer et al., 2000; Scarbrough et al., 2001; Wheeler et al., 2002). In a multi-year 300-day grazing experiment, Troxel et al. (2014) found total grazing days were extended 16$\pm$20.4 days by using rotational grazing systems with bermudagrass stockpiles. Additionally, Senturklu and Landblom (2017) concluded that a stockpiled grass and crop residue grazing system reduced cow wintering cost relative to conventional grazing systems. Poore and Drewnoski (2010) found that stockpiled forages had the potential to meet minimum nutrient requirements for early gestation or non-lactating cows in tall fescue paddocks. Stockpiled forages, especially bermudagrass stockpiles, have less nutritive value than non-dormant warm-season grasses. Respiration, leaf drop, and the leaching of nutrients cause declines in the nutritive value of stockpiled forages (Ocumpaugh & Matches, 1977; Matches & Burns, 1995; Baron et al., 2004). The decline in nutritive value could result in the need for extra feed supplementation (Kulahunga et al., 2016). Kothmann et al. (1971), Hart et al. (1998), Aiken and Bransby (1992), Gillen and Sims (2002), and Beck et al. (2016) found that increasing stocking rate decreases cow-calf performance when forage leaf drop occurs at a higher rate than the regrowth of vegetation. Economically, Beck et al. (2016) also found that highest net returns per hectare and per cow increased with increased stocking rates in high precipitation environments. This is due to decreasing labor costs and increasing sales revenue over total observed expenses.

Due to additional challenges associated with cow-calf research relative to stocker research, most overwinter forage grazing studies have focused on stocker operations (Rouquette, 2015). While grazing season extension practices have been economical in stocker cattle, cow-calf operations have not had the same level of investigation. The objectives of this study were to (i) estimate the effects of grazing system on calf birth weight (BWT), 205-day adjusted weaning weights (AWT), cow body condition score (BCS) prior to breeding, total kg of hay fed per month, and total kg of cube supplement fed per month, (ii) find the system with the greatest economic return to land, management, and farm overhead, and (iii) determine how sensitive base-case results are by *ceteris paribus* changes in fertilizer price, feed price (hay and cubes), labor price, and time devoted to feeding.

Materials and Methods

<u>Experimental description</u>

All animal procedures in the following study were performed under the recommendations of the Guide for Care and Use of Agricultural Animals and Research and Teaching and were approved by the Noble Research Institute's Animal Care and Use Committee (IACUC) prior to the initiation of the study in 2016.

Data were from a four-year completely randomized design grazing experiment (2016-2020) conducted in south central Oklahoma at the Noble Research Institute's Pasture Research and Demonstration Farm near the community of Ardmore, Oklahoma, U.S.A. (34°13'00.9"N, 97°12'31.1"W) on nine 16 ha paddocks. Each paddock had three sub-paddocks to allow rotational grazing. Soils within the study area consist of Chickasha loam (fine-loamy, mixed, active, thermic Udic Argiustolls) and Renfrow silt loam (fine, mixed, superactive, thermic Udertic Paleustolls). Assigned systems include: (1) 16 ha of bermudagrass pasture supplemented with hay and 20% range cube supplement (CONTROL), (2) 16 ha of bermudagrass pasture with 4 ha of bermudagrass stockpile

(25% of paddock) and 4 ha of interseeded small grain winter pasture (25% of paddock) (SPINT), and (3) 13 ha of bermudagrass pasture with 4 ha of bermudagrass stockpile (25% of paddock) and 3 ha of summer and winter annual cropland grazing (SPCROP). Data for three replicates of each system were collected in the study. Cow performance variables recorded include weight and body condition score (BCS) prior to breeding, weight and BCS at calving and weaning, and weight and BCS post breeding cycle. Calf performance variables of BWT, weight prior to breeding of dam, and AWT were recorded.

Agronomic practices

The chronology of forage management practices is reported in Table 2.1. After calving begins, a soil sample from each paddock was obtained by randomly taking 12-15 soil cores to a 15 cm depth, then combing the cores for a soil sample that represented the paddock area. Fertilizer applications began in May, with each paddock receiving equal blanket applications of nitrogen (N) at a rate of 112 kg ha^{-1}. Phosphorus (P), potassium (K), and lime (100% ECCE equivalent) applications were completed based upon soil test results obtained from the paddock soil samples. Urea (46-0-0), diammonium phosphate (18-46-0), and potash (0-0-60) were sources for N, P, and K, respectively. In the CONTROL, P was applied to replications 1, 2, and 3 at a rate of 52 kg ha^{-1} in 2016 and 2017, K was applied to replications 1 and 3 at 34 kg ha^{-1} in 2017, and lime was applied to replications 1, 2, and 3 at 4.48 MT ha^{-1} in 2017. In the SPINT pasture, P was applied to replications 1, 2, and 3 at 52 kg ha^{-1} in 2016 and 2017, K was applied to replications 1, 2, and 3 at 56 kg ha^{-1} in 2016 and at 34 kg ha^{-1} in 2017, and lime was applied to replications 1, 2, and 3 at 4.48 MT ha^{-1} in 2017. In the SPCROP system, P was applied to replication

2 at 52 kg ha^{-1} in 2016 and to replication 2 and 3 at 52 kg ha^{-1} in 2017, K was applied to replications 1 and 3 at 56 kg ha^{-1} in 2016 and to replications 1, 2, and 3 at 34 kg ha^{-1} in 2017, and lime was applied to replications 1 and 3 at 4.48 MT ha^{-1} in 2017. Stockpiled bermudagrass and winter wheat received an additional top-dress of 56 kg ha^{-1} N and 67 kg ha^{-1} N each year, respectively, in both the SPINT and SPCROP systems.

Herbicide applications were made to terminate cropland (wheat and CC) and control annual weeds in bermudagrass pasture. All pastures were sprayed with picloram based herbicides (Grazon P+D, Corteva Agroscience, Wilmington, Deleware, U.S.A.) at a rate of 3.5 L ha^{-1} in 2016 and 2.8 L ha^{-1} in 2017, 2018, and 2019 to control broadleaf annual weeds.

In the SPCROP system glyphosate (Ranger Pro, Monsanto, Creve Coeur, Missouri, U.S.A.) was used as a burn down treatment in September prior to seeding fall winter pasture and again in May prior to the planting of summer cover crops. A rate of 2.1 L ha^{-1} was applied in 2016 and 2017, and a glyphosate plus 2,4-D dicamba (Brash, WinField United, Arden Hills, Minnesota, U.S.A.) mix was applied at 1.4 L ha^{-1} 2,4-D dicamba and 2.1 L ha^{-1} glyphosate (40% dicamba and 60% glyphosate) in 2018 and 2019.

Bermudagrass stockpile hectares in the SPINT and SPCROP systems were over-seeded with annual ryegrass (*Lolium multiflorum* L.) at a bulk seeding rate of 22.4 kg ha^{-1} in mid-August of year one. Following year one, annual ryegrass did not require further seeding as it successfully started to self-propagate. In the SPCROP and SPINT systems, winter wheat was no-till drilled in mid-September of each year. Prior to planting, the SPINT paddocks were grazed to a 15 cm maximum forage height and the 3 ha of cropland in the SPCROP system was sprayed either with glyphosate or a glyphosate plus 2,4-D dicamba mix to terminate the residual cover crop. Wheat was planted to an approximate seeding depth of 2.5 cm. Gallagher wheat was planted in 2016 and 2017 and NF101 wheat was planted in 2018 and 2019. Both varieties were planted at a rate of 134.50 kg ha^{-1}.

The summer CC mix (40% legume and 60% grass) for the SPCROP system was planted in late-May at a rate of 33.63 kg ha^{-1}. CC mixes varied by year, and included 6.73 kg ha^{-1} iron and clay cowpeas, 6.73 kg ha^{-1} soybeans (*Glycine Max* L.), 3.36 kg ha^{-1} sunn hemp (*Crotalaria juncea* L.), 3.36 kg ha^{-1} pearl millet (*Pennisetum glaucum* L.), 2.24 kg ha^{-1} German (foxtail) millet (*Panicum italicum* L.), 2.24 kg ha^{-1} browntop millet (*Urochloa ramosa* L.), 4.48 kg ha^{-1} brown midrib grazing corn (*Zea mays* L.), and 3.36 kg ha^{-1} buckwheat (*Fagopyrum esculentum* L.) in 2016 and 2017. In 2018 and 2019 the CC mix was 6.73 kg ha^{-1} pearl millet, 3.36 kg ha^{-1} okra (*Abelmoschus esculentus* L.), and 23.54 kg ha^{-1} iron and clay cowpeas.

Rainfall amounts were consistently above 30-year average levels for the experimental area in the late winter/early spring months, below average in summer months, and variable in the fall/early winter months. Recorded rainfall for the experimental area is given in Table 2.2. Dry spans, especially those associated with summer CCs, hindered crop growth and performance. Overall, total recorded rainfall was above the 30-year average throughout the experimental period, but individual years varied heavily from long-term average trends.

Cow, breeding bull, and calf management

In March of 2015, prior to the initiation of the study, 90 high percentage Angus (*bos taurus*) cows were selected from the Noble Research Institute's cowherd and assembled at the Pasture Research and Demonstration Farm (previously described) for breeding. In May 2015, all cows went through an estrous synchronization program (7-day CIDR-PG (controlled internal drug release, Pfizer, New York, NY; Lutulyse, Zoetis, Parsippany-Troy Hills, NJ) followed by a timed artificial insemination (AI) to a Hereford bull. All 90 cows were then exposed to four Hereford bulls for 60 days. Bulls were 18 months of age in year one and were maintained through the course of the study. One bull had to be replaced due to a foot injury but was replaced with a bull of similar age and breeding. Two additional bulls were added in 2016. After the 2015 breeding, the breeding was done through natural service only with cows being exposed from mid-May to mid-July and calving mid-February to the end of April. The same bulls were assigned to the same group of cows over the course of the study. Over the breeding period and prior to the start of the study in October, 2015, cows were rotationally grazed across all treatment paddocks. In October 2015, the mature (4.4 ± 0.79 yr of age) high percentage Angus (*Bos taurus*) cows (*n* = 90) with an initial body weight (BW) of 544 ± 59.9 kg and body condition score (BCS 1 to 9-point scale with 1 = extremely thin and 9 = obese) of 5.5 ± 0.6 were sorted by weight and allocated to groups of 10 (*n* = 9) for CONTROL, SPINT, and SPCROP winter pasture systems. Once assigned to a treatment, cows would remain in the treatment unless they were open (failed to breed) or failed to wean a calf (calf death or injury) in which case they were removed from the study and replaced with a cow of similar age, breed type, BW and BCS. In some instances, a cow that failed to wean a calf, but was reproductively sound, was bred and could return to the study as a replacement the following year. Treatment groups were co-mingled between replicates for the breeding season. From October to May each year, cows remained in their assigned treatment replications. Cows were stocked on the paddocks at a rate of 0.62 cow-calf pairs ha^{-1} (10 cow-calf pairs per paddock per year, 30 per system per year). Animal management and feeding activities by month are summarized in Table 2.1.

Veterinary practices were completed following Beef Quality Assurance (BQA) protocols. In all years, pregnancy was determined via ultrasound. If pregnancy status was unable to be determined via ultrasound, blood samples were drawn and analyzed for the presence of pregnancy specific glycoproteins. In 2016, cows were de-wormed using injectable de-wormer at pre-breeding (LongRange (eprinomectin), Merial Animal Health, Duluth, Georgia, U.S.A.) at a rate of 1 mL per 50 kg of body weight subcutaneous injection hd^{-1} and drench wormer (Valbazen (benzimidazole), Zoetis, Parsippany-Troy Hills, New Jersey, U.S.A) at a rate of 4 mL hd^{-1} per 45 kg of body weight at weaning. Cows were also vaccinated at pre-breeding for bovine rhinotracheitis-virus (IBR), bovine viral diarrhea (BVD) parainfluenza-respiratory syncytial virus (BRSV), $parainfluenza_3$ (PI_3), campylobacteriosis, and leptospirosis (CattleMaster 4+VL5, Zoetis, Parsippany-Troy Hills, New Jersey, U.S.A) in a 5 mL subcutaneous injection hd^{-1}. Protection from horn flies, face flies, and lice was given using separate pour-on insecticide treatments. The pre-breeding application of insecticide (Ultra Saber (lambda-cyhalothrin), Merck Animal Health, Kenilworth, New Jersey, U.S.A) was administered at a rate of 15 mL hd^{-1} per head. The weaning period insecticide application (Cylence (cyfluthrin), Bayer Animal

Health, Shawnee, Kansas, U.S.A) was administered at 24 mL hd^{-1} per head. Insecticide applications were made in accordance to label directions.

In 2017, cows were de-wormed in the same manner as 2016, vaccinated for Clostridium Chauveoi-Septicum-Novyi-Sordellii Perfringens Types C & D – Moraxella Bovis Bacterin-Toxoid (Calvary 9, Merck Animal Health, Kenilworth, New Jersey, U.S.A) in a 2 mL subcutaneous injection hd^{-1} pre-breeding, infections bovine rhinotracheitis-virus (IBR), bovine viral diarrhea (BVD) parainfluenza-respiratory syncytial virus (BRSV), $parainfluenza_3$ (PI_3), campylobacteriosis, and leptospirosis (Bovishield Gold FP5+VL5, Zoetis, Parsippany-Troy Hills, New Jersey, U.S.A) in a 2 mL subcutaneous injection hd^{-1} pre-breeding, infections bovine rhinotracheitis-virus (IBR), bovine viral diarrhea (BVD), parainfluenza-respiratory syncytial virus (BRSV), $parainfluenza_3$ (PI_3), campylobacteriosis, and leptospirosis (CattleMaster 4+VL5, Zoetis, Parsippany-Troy Hills, New Jersey, U.S.A) in a 5 mL subcutaneous injection hd^{-1} at weaning, and Clostridium Chauveoi-Septicum-Novyi-Sordellii Perfringens Types C & D – Moraxella Bovis Bacterin-Toxoid (Bovilis 20/20 Vision 7 with Spur, Merck Animal Health, Kenilworth, New Jersey, U.S.A) in a 2 ml injection hd^{-1} at weaning. Pour-on insecticide in 2017 was administered as a 15 mL application in pre-breeding (Ultra Saber, Merck Animal Health, Kenilworth, New Jersey, U.S.A).

Cow veterinary practices in 2018 were identical to 2017, with the exception of the weaning period administration of Clostridium Chauveoi-Septicum-Novyi-Sordellii Perfringens Types C & D – Moraxella Bovis Bacterin-Toxoid (Bovilis 20/20 Vision 7 with Spur, Merck Animal Health, Kenilworth, New Jersey, U.S.A) being omitted.

Cow worming and pre-breeding vaccination practices in 2019 were identical to 2017. Additionally, cows were given pre-breeding synchronizing injections of cloprostenol (Estrumate, Merck Animal Health, Kenilworth, New Jersey, U.S.A) and gonadorelin (Fertagyl, Merck Animal Health, Kenilworth, New Jersey, U.S.A) at a rate of 2 mL hd^{-1} and 2 mL hd^{-1}, respectively. Cows were also administered a progesterone controlled internal drug release (CIDR) insert (CIDR, Zoetis, Parsippany-Troy Hills, New Jersey, U.S.A) pre-breeding for enhanced estrous synchronization. Pour-on insecticides included a 15 mL hd^{-1} pre-breeding application (StandGuard, Elanco, Greenfield, Indiana, U.S.A.) and a 15 mL hd^{-1} weaning application (Ultra Saber, Merck Animal Health, Kenilworth, New Jersey, U.S.A).

Breeding bull veterinary practices followed the same chronology and protocol as cow health practices, with the exception of no reproductive synchronization practices being used. Bulls underwent and had to pass a breeding soundness examination yearly prior to turnout.

Each year at calving, calves were weighed, vaccinated, and bulls castrated. Calf veterinary practices followed BQA protocols. At birth calves were given a vaccination for infectious bovine rhinotracheitis-virus (IBR), and diarrhea parainfluenza-respiratory syncytial virus (BRSV) (Bovi Shield Gold 5, Zoetis Inc., Kalamazoo, Michigan, U.S.A.).

Forage management

Timing of hay feeding and protein supplementation were based upon available forage within paddocks. Pasture biomass in dry matter (DM) ha^{-1} was measured prior to cattle rotating within pastures. Grazing rotation occurred when approximately 60% of the total forage biomass of the pasture had been consumed. Forage biomass was monitored using a monthly calibrated rising plate meter (Jennquip EC09 - Jennquip - Feilding, New Zealand) using regression calibration equations developed for each system. Calibration was done by taking 30 clipped measurements from a 38.1 cm by 38.1 cm quadrant frame that represented the full range of forage mass available. The regression calibration equations were developed from these clipped measurements from procedures described by Cho, et al., 2019.

In all systems, hay and cube supplementation began when bermudagrass DM declined below 1,121 kg ha^{-1} (below approximately 15.25 cm canopy height). Forage nutritive value of hay (i.e. crude protein (CP), TDN, neutral detergent fiber, acid detergent fiber) and stage of gestation determined the amount of supplementation required (NRC, 2016). Average hay and cubes fed (kg) are presented by month graphically in Figure 2.1. Fed hay was purchased from sources outside the study area and weights of fed bales were recorded prior to feeding. Hay and cube supplementation continued until bermudagrass pasture accumulated greater than 1,121 kg ha^{-1} DM (above approximately 15.25 cm canopy height). Hay feeding began in October, peaked in February, and then steadily declined until bermudagrass forage was sufficient in May. Cube feeding was similar, with feeding beginning in November, increasing steadily to a peak in February, and then declining until cube feeding ceased in May.

Hectares devoted to bermudagrass stockpile were grazed short (approximately 10 cm height) by mid-August of each year. Stockpile areas were then fertilized with N and deferred from grazing to allow fresh stockpile to accumulate until the first killing frost (start of warm-season grass dormancy). Warm-season grass dormancy typically occurs in mid-November. Stockpile bermudagrass paddocks were continuously grazed until a utilization level of 65% had been obtained (15 cm height) and bermudagrass leaves had been removed. Cow body condition score was carefully monitored during this period as well and if a decline in body condition was noted, cows were removed.

Interseeded pasture was grazed until the emergence of winter wheat. At emergence, grazing was deferred to allow for winter pasture establishment. Interseeded pasture grazing began when the total DM ha^{-1} accumulated at least 1,345 kg ha^{-1}. Once this DM threshold was reached, the cows were continuously grazed on the paddocks until wheat was grazed out in April. Prior to continuous grazing, cows were allowed access to the wheat for approximately four hours per day as a supplemental protein source. After four hours cows were removed from the paddock and fed hay.

Residual CC in the SPCROP system was chemically terminated before establishing winter wheat in mid-September. Cropland wheat was allowed to properly emerge and establish to a total DM ha^{-1} threshold of at least 1,345 kg ha^{-1} before grazing was initiated. After which, cropland was grazed for four hours every third day. On days cattle were not grazing wheat pasture, they returned to bermudagrass pasture and were supplied hay and cube supplement as needed. At the close of the winter grazing season (April-May), cattle were allowed to fully graze out winter pasture before CC establishment. CC were no-till seeded into cropland hectares and grazing began when forage mass reached 1,345 kg ha^{-1}. Cows were allowed to graze the cover crop to a 50% utilization rate.

Statistical analysis

Statistical analyses of the collected data were conducted using the MIXED Procedure in SAS (version 9.4) (SAS institute, 2012). One-way analysis of variance (ANOVA) was used to estimate the effect of treatments on measures of animal performance (calf BWT, calf weight prior to breeding the dam, and AWT) and feed (hay and protein cubes) variables. Differences of least squares means were compared using least significant difference (LSD) tests and separated using the pdmix800 integrated macro program (Saxton, 1998). The model is represented as

$$y_{st} = \mu_s + \tau_t + \varepsilon_{st} \tag{3}$$

where y_{st} represents the response variable in system s and year t for each animal performance variable (i.e. BWT, calf weight prior to breeding of the dam, AWT); μ_s is a system fixed effect where $s \in$\{CONTROL, SPINT, SPCROP\}; τ_t is a year random effect where $\tau_t \sim N(0, \sigma^2)$; and ε_{st} is the error term where $\varepsilon_{st} \sim N(0, \sigma^2)$. Likelihood ratio tests revealed there was a random year effect associated with the animal performance variables at the 95% confidence level.

Feeding variables include the total kg of hay and cubes fed per year in each system. The ANOVA is similar to Equation 1 except monthly data were used:

$$f_{smt} = \gamma_s + \theta_{mt} + \varepsilon_{smt} \tag{4}$$

where f_{smt} represents the response variable of system s, month m, and year t for the feeding variables (total kg hay and cubes fed); γ_s is a system fixed effect; θ_{mt} is a month × year random effect where $\theta_{mt} \sim N(0, \sigma^2)$; and $\varepsilon_{smt} \sim N(0, \sigma^2)$.

<u>Economic methods</u>

Enterprise budgeting was used to calculate expected revenues, costs, and net return for each grazing system (AAEA, 2000). Revenues were calculated as the least squares mean AWT multiplied by the price of produced heifers and steers in \$ kg^{-1} (BIF, 2018). Calf prices were obtained from ten years (2011-2020) of Oklahoma City National Stockyards sales data for medium to large number one steers and heifers. All sales prices were linearly interpolated using a price slide for better representation of received prices in \$ kg^{-1} with increasing weights. The price slide associated with steers was \$-0.002 kg^{-1} kg^{-1} and the price slide associated with heifers was \$-0.002 kg^{-1} kg^{-1}. All calves were assumed sold upon weaning.

Input prices were from local supply dealers in January 2022. Paddocks were assumed to be in close proximity to one another, and as such, labor to feed cubes was assumed to take approximately 6 minutes of labor and feeding one large round bale consumed approximately 10 minutes of labor. Rotational grazing labor costs were not considered in the enterprise budgets, as they were similar in all systems. Custom rates for fertilization, spraying, and no-till were from 2020 Oklahoma State University statewide averages (Sahs, 2020). To find proportionate fuel, lube, repair, labor, and fixed machinery costs, custom rates were further broken down based upon known percentages in no-till establishment practices. Of the total custom rates 14% were allocated to labor, 46% to fuel, lube, and repairs, and 40% to fixed machinery depreciation expenses. Chemical product prices were based upon the brand name product used in the experiment. Fertilizer prices were based upon the applied sources of N, P, K, and lime. Fertilizer and soil amendment quantities applied were based upon real application quantities of N (as a mobile nutrient dependent upon system) and an average application ha^{-1} of P and K. Lime applications were based upon a known ratio of 13/4 lime to nitrogen to keep soil pH constant. To account for the current high fertilization costs, fertilizer (N, P, and K) prices were sourced from USDA ERS average U.S. farm prices of selected fertilizers. Twenty-year average (1995-2014) U.S. fertilizer prices revealed that current N, P, and K prices have increased by 150%, 217%, and 132%, respectively (USDA, 2019[b]). As such, the 20-year average fertilizer prices were used in the economic analysis. Operating costs were subjected to a 5.5 percent interest rate to calculate the opportunity costs of capital for each system.

Economic results of tested treatments are likely sensitive to *ceteris paribus* changes in input prices and labor requirements. As a result, sensitivity analysis was conducted on variables that could change the most economical system. Variables of interest included the cost of nitrogen, the cost of feed (hay and cubes), the wage rate, and feeding labor requirements for hay and cubes. Nitrogen prices were changed by +30%, -30%, and +70% of base-case prices. Given the current high price of nitrogen relative to previous years, an increase of 70% represents a scenario similar to prices in early 2022. The ten-year average price of dry hay (2011-2020) did not reveal any change in the price of hay from the current price (USDA, 2019[a]). To account for price uncertainty in hay and cube production inputs, a potential hay and cube price change of +30%, -30%, and +50% from base-case prices were considered. Wage rates were changed to +30%, -30%, and -50% from base-case hourly wages to represent additional or reduced feeding and machinery labor costs. Labor assumptions for feeding protein cubes were increased from 6 minutes to 10, 15, and 20 minutes per feeding. Labor requirements for feeding hay were increased from 10 minutes to 15, 20, and 25 minutes per 1.52 m x 1.83 m round bale. This analysis represents the possibility of different farms having additional travel distances to storage facilities and between paddocks.

Results and Discussion

Animal performance

The results of the statistical analysis of animal performance variables are reported in Table 2.3. Overall, calf BWT was not significantly different ($P = 0.2733$), with a range of 1.21 kg. AWT between systems was also not statistically different ($P = 0.8694$). The increased calf weights associated with creep grazing exhibited in Apple et al., 1991 and Apple et al., 1993 were associated with fall calving cows. In the experiment reported here, spring calves did not have access to the cool-season forage due to being sold before the establishment of winter wheat pasture. Calf body weight increases would be more likely in fall calving cows. This also differs slightly with Beck et al., 2016, which focused on stocking rate in bermudagrass stockpiling systems with complementary cool-season forages in spring-calving operations. Beck et al. concluded that the more intensive stockpiling and cool-season forages produced calf weaning weights that were significantly lower than continuous grazing without additional grazing extension practices. Cows at higher stocking rates on stockpiled forage typically had lower body condition scores, and as such this was reflected in calf weaning weights.

Cows had similar BCS prior to breeding ($P = 0.0727$) at the 95% confidence level. In each system, BCS was above ideal levels (ideal being 5 to 6), making them over-conditioned at breeding (Walker, 2017). Although high, similar BCS affirms that the combination of forage and supplementary hay and cubes would have similar potential re-breeding success.

Additional feed through hay and cube supplementation varied between systems. Total kg of cubes fed per month were highest in the CONTROL system ($P < 0.0001$) at 229 kg and numerically higher in the SPCROP system relative to the SPINT system, with 177 kg and 155 kg fed, respectively. Because the SPCROP and SPINT systems allowed cattle to graze winter wheat pasture, which has a relatively high concentration of CP, the need for increased protein-based supplement was lower. This is consistent with Apple et al. (1991), Apple et al. (1993), Dillard et al. (2018), Hoveland et al. (1978), Rouquette (2017), and Mullenix and Rouquette (2017).

Total hay fed per month was highest in the SPCROP system ($P = 0.0036$) at 2,464 kg. A total of 1,850 kg of hay was fed per month in the CONTROL system, which was numerically higher than the SPINT system which utilized 1,604 kg of fed hay per month. Even though wheat pasture has high CP, the reduction of 3 ha of pastureland in the SPCROP system reduced potential forage through dormant bermudagrass. As such, additional protein from cubes was not needed, so cattle were fed hay to meet energy requirements.

Economics

With little variation in animal performance, economic results were determined by differences in costs. Sources of average per hectare revenues, costs, and associated net returns are in Table 2.4. Sources of revenue were limited to the sale of calves produced by each system. Because the least squares means of calf AWT did not differ by treatment, the total kg ha^{-1} also did not differ. Steers received \$3.73 kg^{-1} and heifers received \$3.51 kg^{-1} on average. The average price received for calves, regardless of sex, was \$3.62 kg^{-1}. This average, while equal to the arithmetic mean, is the weighted average based upon sex. This indicates that approximately 50% of the calves were heifers and 50% were steers, which is what is expected, on average. Gross revenue was \$560 ha^{-1}, \$557 ha^{-1}, and \$550 ha^{-1} for the CONTROL, SPCROP, and SPINT systems, respectively. Because gross revenue was similar between systems, the factors that decided the most economical system were the costs associated with seed, feed, machinery, and fertilizer costs.

The CONTROL system did not require winter or summer seeding, so it had no seed costs. Both SPINT and SPCROP systems used winter wheat seed for wheat pasture and annual ryegrass seed for the stockpile, but the SPCROP system required 1 ha less winter seed, resulting in the SPINT system being \$6 ha^{-1} more costly for cool-season seeding. The CC seed for the SPCROP system cost \$13 ha^{-1}. The SPCROP system had an average cost of \$26 ha^{-1} for winter and summer seed. This is \$7 ha^{-1} more than the SPINT system and \$26 ha^{-1} higher than the CONTROL system.

Results of bermudagrass stockpile, cropland, and winter wheat interseeded systems on reducing feed costs were mixed. Feeding costs were highest in the SPCROP system at \$168 ha^{-1}. The SPINT system had the lowest feed cost of \$118 ha^{-1}, while the CONTROL system had feed costs slightly less than the SPCROP system at \$152 ha^{-1}. As such, the feeding costs in SPCROP were \$16 ha^{-1} and \$50 ha^{-1} higher than the CONTROL and SPINT systems, respectively. The cost of feeding labor mirrored the feed costs with the SPCROP, CONTROL, and SPINT systems requiring \$19 ha^{-1}, \$18 ha^{-1}, and \$14 ha^{-1} in labor, respectively.

Machinery costs varied due to increased herbicide and planting needs in the SPINT and SPCROP systems. The SPCROP system had the most machinery usage. Relative to SPINT system and the CONTROL, respectively, the SPCROP system resulted in a \$2 ha^{-1} and \$4 ha^{-1} increase in labor charges, a \$5 ha^{-1} and 12 ha^{-1} increase in fuel charges, and a \$3 ha^{-1} and \$10 ha^{-1} increase in fixed machinery ownership costs. When summed together, the SPCROP system's machinery costs were \$56 ha^{-1}, the SPINT system's costs were \$46 ha^{-1}, and the CONTROL system's machinery costs were \$31 ha^{-1}.

Fertilizer costs accounted for 19%, 22%, and 18% of all cash costs in the CONTROL, SPINT, and SPCROP systems, respectively. Differences in cost were most evident in the N and lime applications. The SPCROP system required the most fertilization and soil amendment applications at a cost of \$84 ha^{-1}. This was \$5 ha^{-1} higher than the SPINT system at \$79 ha^{-1} and \$14 ha^{-1} higher than the CONTROL system at \$70 ha^{-1}.

Because the SPCROP and SPINT systems required more seed and machinery usage, both SPCROP and SPINT systems were more costly than the conventional CONTROL system. Total cash operating costs were \$457 ha^{-1}, \$364 ha^{-1}, and \$364 ha^{-1} for the SPCROP, SPINT, and CONTROL systems, respectively. Total costs, including average annual fixed machinery ownership costs and breeding stock ownership costs, were \$654 ha^{-1}, \$452 ha^{-1}, and \$446 ha^{-1} for the SPCROP, SPINT, and CONTROL systems.

While gross revenues were similar, the CONTROL system had \$10 ha^{-1} and \$3 ha^{-1} higher gross revenue than the SPINT and SPCROP systems, respectively. Costs incurred were highest in the SPCROP system, but relatively similar in the CONTROL and SPINT systems, with the SPINT system being \$6 ha^{-1} more costly. The CONTROL system was the most economical, realizing a net return of \$114 ha^{-1}, which was \$16 ha^{-1} higher than the SPINT system which had a net return of \$98 ha^{-1} and \$110 ha^{-1} higher than the SPCROP system that had a net return of \$4 ha^{-1}.

Changes in input prices could result in changes in the economically preferred system. Result of the sensitivity analysis are reported in Table 2.5. Base-case fertilizer costs accounted for high percentages of the total system cash cost. Much of these costs were from N applications. The SPCROP system was most sensitive to N price changes, followed by the CONTROL and SPINT systems. A 30% reduction in N price resulted in the CONTROL being \$18 ha^{-1} and \$108 ha^{-1} more profitable than the SPINT and SPCROP systems, respectively. When N prices increased by 30%, the CONTROL and SPINT system had positive returns at \$97 ha^{-1} and \$81 ha^{-1}, respectively. Compared to the SPCROP system, the net returns of the CONTROL and SPINT system were \$112 ha^{-1}

and \$98 ha^{-1} higher. A 70% increase in N price represents prices more comparable to current prices and resulted in sharply declining net returns in all systems. Net returns in the CONTROL system were \$73 ha^{-1}, which were \$14 ha^{-1} and \$116 ha^{-1} higher than the SPINT and SPCROP systems, respectively. At no point did the economically preferred system shift from the CONTROL system, implying that positive returns were strongest in CONTROL in an uncertain N market.

Due to its intensive hay feeding, the net return of the SPCROP system was the most sensitive to changes in hay prices, followed by the CONTROL and SPINT systems, respectively. When hay price decreased by 30%, the CONTROL, SPINT, and SPCROP systems realized net returns of \$144 ha^{-1}, \$123 ha^{-1}, and \$44 ha^{-1}. As prices increased, however, the relative gap in net returns between SPCROP and the CONTROL and SPINT systems widened. When prices increased by 30%, SPCROP had additional losses of \$120 ha^{-1} and \$108 ha^{-1} relative to CONTROL and SPINT, respectively. A 50% increase in hay prices resulted returns of \$65 ha^{-1}, \$55 ha^{-1}, and \$-62 ha^{-1} in CONTROL, SPINT, and SPCROP, respectively.

Because cube feeding was highest in the CONTROL system, it was also the most responsive to changes in price. When cube prices decreased by 30%, the CONTROL, SPINT, and SPCROP systems realized positive returns of \$124 ha^{-1}, \$110 ha^{-1}, and \$18 ha^{-1}, respectively. Increasing cube prices by 30% resulted in net returns of \$96 ha^{-1}, \$86 ha^{-1}, and \$-10 ha^{-1} in the CONTROL, SPINT, and SPCROP systems, respectively. With a 50% increase in cube price scenario, net returns in the CONTROL system were \$6 ha^{-1} and \$102 ha^{-1} higher than the SPINT and SPCROP systems, respectively, allowing it to remain the most economical system.

Incremental changes in the prevailing wage rate for labor had little effect on per hectare profitability. As expected, the CONTROL and SPCROP systems were more responsive to changes in price due to the increased need of hay and cube supplementation. The SPCROP system was additionally responsive to labor price changes as it required greater amounts of machinery labor relative to the SPINT and CONTROL systems. Increasing the wage by 30% resulted in net returns in the CONTROL, SPINT, and SPCROP systems to decline to \$107 ha^{-1}, \$91 ha^{-1}, and \$-4 ha^{-1}, respectively. Reducing the wage by 30% increased net returns by \$7 ha^{-1}, \$7 ha^{-1}, and \$8 ha^{-1} in the CONTROL, SPINT, and SPCROP systems, respectively. A wage rate 50% of the base-case caused profits to be \$126 ha^{-1}, \$109 ha^{-1}, and \$18 ha^{-1} in the CONTROL, SPINT, and SPCROP systems, respectively. Although the SPCROP system benefited the most from declining wages, its comparatively lower initial net returns did not allow changes in ordinal ranking. The CONTROL system remained the most profitable system in all wage rate scenarios.

Initially it was assumed that hay and cube storage facilities were located near the pastures. However, relaxing this assumption to assume further distances and time necessary for feeding hay and protein cubes consistently decreased net returns in all three systems. Results show that for each additional minute required to feed a round bale increased average costs by \$1.04 ha^{-1}, \$0.86 ha^{-1}, and \$1.33 ha^{-1} in the CONTROL, SPINT, and SPCROP systems, respectively. On average, one additional minute to feed protein cubes increased costs by \$1.52 ha^{-1}, \$1.07 ha^{-1}, and \$1.12 ha^{-1} for the CONTROL, SPINT, and SPCROP systems, respectively. Even at the maximum assumed time requirements for hay and cube feeding (e.g., 25 minutes for hay and 20 minutes for cubes), the CONTROL system remained the most economical system. The CONTROL and SPINT system had positive profits in all labor requirement scenarios, while the SPCROP system net returns were consistently negative under the possibility of increase feeding labor requirements.

Overall, the results of the study indicate that the bermudagrass plus hay and feed (CONTROL) system commonly utilized by producers in the region is the most economical system. The ordinal preferences by net returns are robust and are unlikely to change with changing input prices or varying requirements for labor to feed hay and cubes.

Conclusions

The goal of this study was to determine the economic feasibility of bermudagrass stockpile and planted annual summer and winter pasture in grazing season extension in cow-calf operations compared to the typical cow-calf production system consisting of a bermudagrass forage base plus winter supplementation of hay and protein cubes. Animal performance results suggested lower need for protein cubes for a system that allows grazing wheat during the cool-season months when bermudagrass pastures were dormant. Moreover, the additional costs of establishing seeded pastures, both in cropland and interseeded into bermudagrass pasture, did not produce enough additional revenue or feed cost savings to support their use compared to the conventional system. The more intensive winter/summer annual and stockpiling systems required higher fertilization and machinery use, resulting in a higher total cost. Finally, the increased dry matter availability through stockpile grazing was not enough to reduce feed costs to make it more attractive economically compared to the common system. Overall, the relative results were not overly sensitive to incremental changes in the prices of inputs or labor requirements for feeding hay and cubes.

Table 2.1. Chronology of pasture and cattle management activities by month and production system.

	Production System[a]			
Production activity	Month	CONTROL	SPCROP	SPINT
Cowherd pre-breeding vaccinations, de-worm and apply external parasite control.	May	x	x	x
Annual weed control on bermudagrass paddocks	May	x	x	x
Chemical burndown prior to CC planting	May		x	
No till drill cover crop	May		x	
Apply N, P, K, and lime to bermudagrass paddocks	May	x	x	x
Breeding period	May-Jul	x	x	x
Apply N to bermudagrass for stockpile	Aug		x	x
Chemically burn down cover crop	Sep		x	
No-till drill wheat seed	Sep		x	x
De-worm and apply external parasite control to cowherd	Oct	x	x	x
De-worm, vaccinate, and apply external parasite control to calves.	Oct	x	x	x
Apply N, P, K to wheat	Oct		x	x
Feed hay	Dec-Apr	x	x	x
Feed protein cubes	Dec-Mar	x	x	x
Feed protein cubes	Apr	x	x	
Cowherd pre-breeding vaccinations, de-worm and apply external parasite control.	May	x	x	x
Annual weed control on bermudagrass paddocks	May	x	x	x
Chemical burndown prior to CC planting	May		x	
No till drill cover crop	May		x	

[a] CONTROL is bermudagrass pasture and conventional hay and cube feeding; SPINT bermudagrass pasture with bermudagrass stockpile and interseeded wheat; SPCROP is bermudagrass with bermudagrass stockpile and cropland summer and winter pasture

Table 2.2. Rainfall in centimeters by month and year at the Pasture Research and Demonstration Farm located near Ardmore, Oklahoma.

Month/Year	2016	2017	2018	2019	2020	Avg.	30-yr avg.
January	1.65	8.41	0.38	5.87	8.86	5.03	4.19
February	4.14	6.5	18.19	6.5	9.47	8.96	5.31
March	8.92	2.79	8.76	6.12	13.69	8.06	6.71
April	20.98	7.7	5.1 1	15.11	6.45	12.56	8.38
May	13.44	13.72	15.34	11.48	-	13.50	14.1
June	9.47	5.92	6.81	13.72	-	8.98	10.69
July	2.24	13.51	5.16	1.47	-	5.60	7.16
August	5.03	17.5	13.89	15.72	-	13.04	6.99
September	6.2	5.23	23.14	10.41	-	11.25	8.08
October	4.04	2.59	32.26	13.61	-	13.13	10.9
November	5.38	0.15	1.35	7.54	-	3.61	5.69
December	2.08	4.6	13.13	2.08	-	5.47	5.79
Total	83.57	88.62	138.41	109.63	38.47	109.16	93.99

Source: www.mesonet.org

Table 2.3. Least square means and standard errors for cow-calf production and feed variables.

	Production System[a]						
	CONTROL		SPINT		SPCROP		
Variable of interest	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.	*P*-value
Calves							
Birth weight (kg)	40.35	0.83	39.60	0.84	39.14	0.84	0.2733
Weight prior to breeding dam (kg)	111.89	3.03	111.28	3.00	109.83	3.01	0.7350
205 adjusted weaning weight (kg)	247.67	3.96	245.90	3.95	247.20	3.95	0.8694
Cows							
Body condition score before breeding	6.81	0.12	6.97	0.12	7.04	0.12	0.0727
Amount of feed required							
Cubes fed per month (kg)	228.56A	34.90	154.61B	35.01	176.72B	35.01	<0.0001
Hay fed per month (kg)	1849.83B	351.14	1603.66B	355.50	2464.18A	355.50	0.0036

[a] CONTROL is bermudagrass pasture and conventional hay and cube feeding; SPINT bermudagrass pasture with bermudagrass stockpile and interseeded wheat; SPCROP is bermudagrass with bermudagrass stockpile and cropland summer and winter pasture

Table 2.4. Calving production, sources of revenues, production costs, and net returns to land, management, and farm overhead by production system.

Animal performance and economic variables	Production system[a]		
	CONTROL	SPINT	SPCROP
Sources of revenue			
Average adjusted 205 day calf weaning weight (kg ha^{-1})	154.48	151.91	154.02
Average price received ($ kg^{-1})	3.62	3.62	3.62
Gross revenue from calves ($ ha^{-1})	559.99	549.64	556.65
Production costs			
Herbicide burndown prior to planting/interseeding ($ ha^{-1})	-	1.46	2.20
Herbicide to control broadleaf weeds ($ ha^{-1})	22.41	22.44	18.58
Cow, calf, and bull health/veterinary practices ($ ha^{-1})	26.19	26.17	26.42
Small grain seed ($ ha^{-1})	-	18.53	12.97
Cover crop seed ($ ha^{-1})	-	-	12.97
Hay and cubes ($ ha^{-1})	151.77	118.22	167.81
Hay and cubes: labor for feeding ($ ha^{-1})	18.48	14.21	18.98
Cost of fencing for rotational grazing ($ ha^{-1})	34.87	34.87	52.29
Cost of water for rotational grazing ($ ha^{-1})	21.25	21.25	21.25
Machinery labor ($ ha^{-1})	4.37	6.47	7.86
Machinery fuel ($ ha^{-1})	14.36	21.28	25.80
Fertilizer (N, P, K, and. Lime) ($ ha^{-1})	70.10	79.00	83.89
Total cash operating expenses ($ ha^{-1})	363.84	363.89	455.66
Interest on operating capital ($ ha^{-1})	20.01	20.01	25.06
Breeding bulls fixed ownership costs ($ ha^{-1})	49.42	49.42	49.42
Machinery fixed ownership cost ($ ha^{-1})	12.48	18.51	22.44
Total cost ($ ha^{-1})	445.75	451.83	552.58
Net returns to land, management, and overhead ($ ha^{-1})	114.24	97.81	4.07
Relative difference in net returns against best system ($ ha^{-1})	0.00	-16.44	-110.17

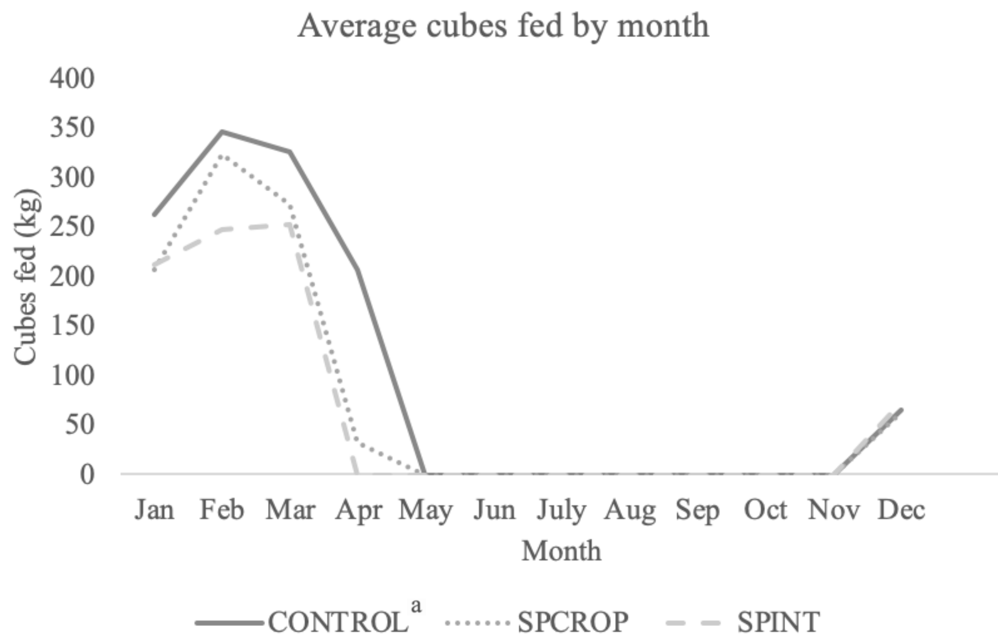
[a] CONTROL is bermudagrass pasture and conventional hay and cube feeding; SPINT bermudagrass pasture with bermudagrass stockpile and interseeded wheat; SPCROP is bermudagrass with bermudagrass stockpile and cropland summer and winter pasture

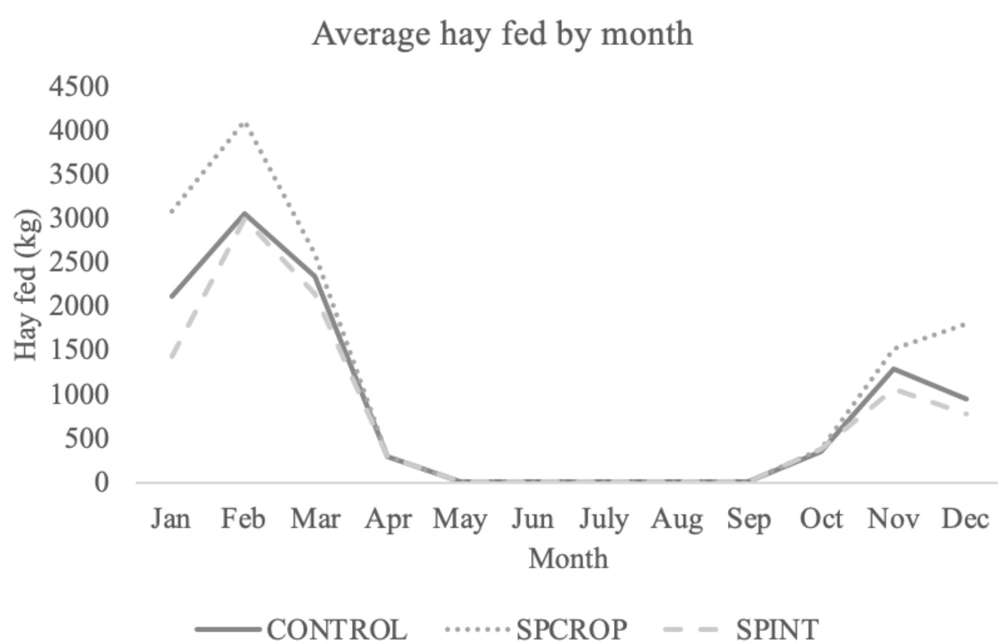
Table 2.5. Expected net returns ($ ha^{-1}) for *ceteris paribus* changes in per unit prices of fertilizer, hay, protein cubes, labor, and time requirements for feeding hay and protein cubes.

Production input	Sensitivity scenario	Price / min	Production System[a]		
			CONTROL	SPINT	SPCROP
Price of N (46-0-0) ($ kg^{-1})	Base-case	0.88	114.24	97.81	4.07
	Base-case -30%	0.62	131.81	114.24	24.30
	Base-case +30%	1.15	96.65	81.39	-16.17
	Base-case +70%	1.50	73.21	59.50	-43.15
Price of hay ($ kg^{-1})	Base-case	0.18	114.24	97.81	4.07
	Base-case -30%	0.12	143.82	123.28	43.61
	Base-case +30%	0.23	84.64	72.35	-35.49
	Base-case +50%	0.26	64.91	55.37	-61.85
Price of cubes ($ kg^{-1})	Base-case	0.87	114.24	97.81	4.07
	Base-case -30%	0.61	123.68	109.76	17.63
	Base-case +30%	1.13	95.78	85.87	-9.50
	Base-case +50%	1.30	83.48	77.91	-18.54
Price of labor ($ hr^{-1})	Base-case	15.00	114.24	97.81	4.07
	Base-case +30%	19.50	106.99	91.27	-4.42
	Base-case -30%	10.50	121.46	104.36	12.55
	Base-case -50%	7.50	126.29	108.73	18.21
Labor requirements for feeding hay (min)	Base-case	10	114.24	97.81	4.07
	Base-case + 50%	15	109.04	93.54	-2.59
	Base-case + 100%	20	103.84	89.26	-9.25
	Base-case + 150%	25	98.65	84.98	-15.91
Labor requirements for feeding cubes (min)	Base-case	6	114.24	97.81	4.07
	Base-case + 67%	10	108.15	93.53	-0.40
	Base-case + 150%	15	100.54	88.18	-5.98
	Base-case + 233%	20	92.94	82.82	-11.56

[a] CONTROL is bermudagrass pasture and conventional hay and cube feeding; SPINT bermudagrass pasture with bermudagrass stockpile and interseeded wheat; SPCROP is bermudagrass with bermudagrass stockpile and cropland summer and winter pasture

Figure 2.1. Average hay and cubes fed by month.





[a] CONTROL is bermudagrass pasture and conventional hay and cube feeding; SPINT bermudagrass pasture with bermudagrass stockpile and interseeded wheat ; SPCROP is bermudagrass with bermudagrass stockpile and cropland summer and winter pasture

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