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Abstract

The third most consumed meat around the world is beef. Despite global growth in demand, cattle markets experience price cycles related to biological production lags causing variability in cash flow and profitability for producers. Price-driven herd size management strategies thus have received attention. This study adds to that literature by analyzing both price and production risk using three herd size management strategies: i) steady state – holding herd size constant; ii) dollar cost averaging – keeping reinvestment constant by varying the number of replacement heifers retained at a constant long run average dollar total; and iii) moving average – using an uptrend/downtrend price signal to lower/increase production in anticipation of future price declines/increases. These strategies are evaluated over the most recent 2004-2014 cattle cycle based on their relative profitability and risk with and without forage variability as a result of weather simulation on forage yields. This analysis is useful for decision makers of medium- to large-scale cow-calf operations. Results suggest that price signal-based strategies can enhance profitability but the managerial cost required for this type of herd size management is deemed larger than its benefit.

Introduction and Literature Review

Cattle (*Bos taurus* L.) production is a vital industry to agriculture in many U.S. states as agricultural commodity cash receipts in 2015 totaled $78.2 billion, equating to 21% of total agricultural commodity sales (Matthews et al., 1999). With an estimated 98.2 million head of beef cattle and calves across the U.S. in July of 2015, changes in the U.S. herd size, due to varying cattle and feed prices as well as weather-driven impacts, can have large economic effects. For example, with the implementation of the Renewable Fuel Standard in 2005, corn value increased making it the most valuable commodity in terms of value of production. However, the record cattle prices from 2012-2015 caused cattle to regain its position as the most valuable commodity in terms of contribution to GDP. These record prices along with declining feed prices have triggered an increase in cattle production and inventories.

This growth in inventory marked the end of one cattle cycle (2004-2014) and the start of a new cycle (2015-2025$\pm$2). The average cattle cycle typically lasts from 8 to 12 years (Matthews et al., 1999) with the length of expansion or herd decline linked to i) beef export/import conditions that are driven by exchange rates and disease outbreaks that in turn can lead to trade restrictions; ii) cattle and feed prices; iii) climatic events; and iv) a long biological production lag (gestation period of 273 days and a requirement of 15 months of age for first breeding) causing herd expansion to be slow compared to possible quick herd liquidation attributed to slaughter (Hughes, 1987). Finally, cow-calf production occurs on pastures and takes up a majority of the beef production cycle in terms of time. Production uncertainty due to drought, flooding as well as wild fires and blizzards is therefore relatively high in beef production when compared to confined animal feeding conditions typical for competing meat products of pork and poultry (Matthews et al., 1999).

While price cycles are common in agricultural production, beef cattle producers are accustomed to an especially lengthy and prominent cycle. Further, when exposed to drought, cattle producers typically have only two possible responses: i) they can either sell cattle until they have enough resources to maintain the remaining herd; or ii) buy additional resources to supplement on-farm supplies (Matthews et. al, 1999). Both of these options have large economic impacts on the supply side of cattle markets. As drought affected much of the U.S. during 2012, producers began selling cattle (for slaughter) in response to low forage availability and drinking water resources, while other producers bought extra forage to maintain their current herd. This simultaneously drove down cattle prices and drove hay prices upward resulting in large losses to cattle producers. National beef cattle and calves inventories declined to a record low of 88.3 million head on January 1, 2014, the lowest recorded inventory since 1954 (National Agricultural Statistics Service, 2015). Eventually, this post-drought inventory led to record high cattle prices in 2014-2015. In addition to record cattle prices, farmers have been faced with increased feed costs due to rising grain prices from 2004-2014 (Dunford, 2012). Dunford states that despite record high cattle prices, high profits are not a guarantee as high feed costs can reduce profits. Managing these price cycles by way of herd size expansion/reduction and acquisition of supplemental feed thus requires careful planning on the part of cow-calf producers in terms of cash flow, income tax repercussions, and risk management (Hughes, 2000). Further, the economic implications of herd size management are greater the larger the cow herd. According to the USDA Economic Research Service (2016), the average cow-calf operation is 40 head, with operations this size or smaller often used as a supplementary income source to off-farm occupations or other farm enterprises. This size category represents only a small portion of the total cattle inventory in the U.S. Operations with 100 head or more, while only 9% of operations, account for 51% of U.S. cattle inventories (Jones, 2017). For operations of this size, proper management of herd expansion or contraction during the cattle cycle plays a more important role for generating long-term profit than with smaller operations. Producers typically make production decisions based upon current prices; however, the results of these decisions do not manifest themselves until several years later when prices tend to be drastically different. Generally, producers expand herd size in response to high prices, which creates a large calf crop several years later (Bentley and Shumway, 1981). The nature of the cattle price cycle dictates that prices have likely declined by the time these calves are marketable, therefore the decision to expand the herd was counterproductive, *ceteris paribus*. This pattern creates a need for a management strategy that looks toward the future and anticipates price cycles. Research by Bentley and Shumway (1981), as well as Trapp (1986), revealed that price-dependent strategies, which react to price cycles, generate larger profits when compared to production strategies that assume constant herd sizes and output prices.

A 2001 study from Iowa State University compared a static, or constant, herd size strategy with i) a constant cash flow strategy where more heifers are sold during low price years and fewer heifers are sold during high price years to maintain constant cash inflow from heifer calf sales; and ii) a dollar cost averaging strategy where investment in the breeding herd is maintained at a long-term average by varying the number of replacement heifers retained in light of changing cattle prices (Lawrence, 2002). The results of that study suggested that a dollar cost averaging strategy was superior to the static and constant cash flow strategies. However, the study acknowledges that they did not consider weather-driven interference with the model's outcome. This is an important limitation as hay and pasture yields can be quite variable in the Mid-southern US. To that end, a study by Lutes and Popp (2015) showed the impacts of weather on cow-calf producer returns in northwest Arkansas. This study utilized the Forage and Cattle Planner (FORCAP), which is a spreadsheet based cow/calf production simulation tool (Popp et al., 2014). Because forage is a large input in cattle production, changes in revenue and expenses from forage production will have a large impact on cash operating profitability of the operation and were important variables excluded from Lawrence's (2002) study.

Using the FORCAP model, the objective of this research is to analyze cow/calf cash operating profitability associated with a fixed land resource. Over the course of one complete cattle cycle (2004-2014), weather uncertainty affects purchases of hay to supplement on-farm forage production, or selling excess hay in the case of surplus. Using historical prices, compared are: i) a static herd size scenario; ii) a dollar cost averaging strategy as proposed by Lawrence (2002); and iii) a moving average price strategy. The latter moving average price strategy is based on a signal of an upward or downward trend in cattle prices using 10 and 27 month moving average prices. When the short-term moving average crosses the long-term average from (above or below) this sends a price trend signal (upward or downward) which triggers a herd size management decision. Finally, cash operating profits or net cash returns over the eleven year period as well as their level of risk (standard deviation and range) and their net present value will be compared to determine the optimal herd size management strategy by quantifying economic implications of strategy choices. The results of this analysis will help medium- to large-scale cow-calf producers choose a strategy based upon price signals that maximizes the profitability of the operation if history were to repeat itself.

Materials and Methods

FORCAP

This analysis uses the Forage and Cattle Planner (FORCAP) as available at http://agribusiness.uark.edu/decision-support-software.php. FORCAP is a decision aid that allows cattle producers to select from a set of default values for production parameters or to choose operation-specific information to analyze the relative profitability of alternative production practices. Pasture and hay acreage, farm size, and cow herd size are key parameters that can be user-modified in FORCAP along with a multitude of other variables such as continuous vs. rotational grazing, choice of stockpiling and winter annuals, forage species mix on pasture and hay land, fertilizer inputs, herd genetics along with stocking rate and animal weights, choice of feed supplement, heifer age at first breeding, breeding failure rates and death losses, calving season, weaning age, choice of input and output price histories as well as vaccination program, veterinary and transport charges. The program also allows tracking of ownership charges for equipment, buildings, fence, and watering facilities but these costs are ignored in this analysis as they were deemed not to vary significantly over the course of a cattle cycle.

Ranch Scenarios

All three herd size management strategies are analyzed using three scenarios that vary with respect to amount of cattle and hay production using alternative fertilizer levels on pasture and hay land. Further, these nine strategies by scenario combinations are differentiated by assuming no weather effects on forage and attendant hay and cattle production as well as the same nine combinations under weather uncertainty. Scenario one utilizes a 100-cow herd with *medium* fertilizer application on hay that consists of 0.25 ton per acre of lime, 100 pounds per acre of ammonium nitrate, and 2 tons per acre of poultry litter, and *low* fertilizer application on pasture, involving 0.25 ton per acre of lime and 0.5 ton per acre of poultry litter. This scenario yields a small hay surplus that is indicative of an operation that relies mainly on cattle revenue as a source of income. Scenario two utilizes a 100-cow herd with the same fertility input on hay land as in Scenario one but increased fertility on pasture by increasing poultry litter to 1 ton/acre to increase hay sales. This scenario thereby has greater diversification in revenue streams as hay sales take on a greater share of farm sales. Scenario three utilizes a 160-cow herd on the same acreage and applies a high level of fertilizer to both hay (0.25 tons/acre of lime, 300 pounds/acre of ammonium nitrate, 3 tons/acre poultry litter) and pasture acres (0.25 tons/acre of lime, 100 pounds/acre of ammonium nitrate, 2 tons/acre poultry litter). Without weather risk, this scenario leads to the same hay sales as scenario one. Scenarios four, five, and six are identical to scenarios one, two, and three, respectively, except weather variability is added by way of satellite imagery analysis capturing differences in photosynthetic activity over time in a production index.

Production Index

Monthly forage production can be tracked historically using imagery and associated NDVI (National Drought Vegetation Index) data collected by LANDSAT. Upon request, this data is publically available and typically yields 2 NDVI values per month for a specific location (30 m resolution). Chosen for this analysis were six pasture/hayland fields in Washington County in Northwest Arkansas. The fields were identified using historical cropland data layer data available through NASS (National Agricultural Statistics Service, 2017) to have assurance that the fields were in pasture or hayland production for the period of the 2004-2014 cattle cycle. Therefore, approximately 12 NDVI values per month were available to create a time-varying vegetation index that would lend itself to capture weather impacts on forage production. To capture changes in forage production, the ratio of an individual month's NDVI value to its eleven-year average for a particular month indicated deviations from weather conditions observed on average over 2004-2014. A value above or below 1 indicates a particularly productive or poor forage production month, respectively. Multiplying this index value by average monthly forage production as a percent of total annual yield by forage species shown in Figure 1, weather induced impacts on forage production could be modeled. The monthly default values used in FORCAP (Figure 1) are based on expert opinion of John Jennings (2013) and Charles West (2013) and are similar to values found in Gadberry (2015) and Huneycutt et al. (1988). Selecting the production index option, as shown in Figure 2, monthly forage production numbers were adjusted by the year's index value and hence impacted forage availability and attendant hay sales or purchases.

Baseline Model Parameters

Each scenario employs a baseline set of parameters designed to resemble a typical Arkansas cow-calf operation. This baseline consists of 320 acres of pasture with 80 acres devoted to hay production. The baseline utilizes rotational grazing which allowed the producer to bale excess forage from pasture acres when available. Additionally, 80 acres of winter wheat are planted yearly to provide forage during the winter months using the winter annual option under the pasture tab (Figure 3). Fertilizer application is varied as described above. Pasture forage species consisted of 25% Bermuda grass (*Cynodon dactylon* L.), 65% fescue (*Festuca arundinacea Schreb.* L.), and 10% clover (*Trifolium repens* L.). Hay forage species consisted of 50% Bermuda grass, 45% fescue, and 5% clover (Figure 3). FORCAP defaults were used for mature/young cow weights, birth weight, weaning weight and age (Figure 4). When necessary, corn is fed as supplementary feed at historical market price to ensure adequate crude protein and TDN intake for maintaining cow body condition. The fall calving season option is selected to reduce breeding failure rate. One herd sire is utilized for every thirty cows. Therefore four herd sires were used in scenarios one, two, four, and five while six herd sires were used for scenarios three and six to accommodate the larger breeding herd in those scenarios. Each year five revenue streams were available to the operation and included sale of weaned steer and heifer calves, cull cows and herd sires, as well as excess hay produced on farm.

Herd Sire and Calving Management

All 100-cow scenarios began with a herd consisting of 83 mature cows, 17 young cows, and 18 replacement heifers. All 160-cow scenarios began with a herd consisting of 133 mature cows, 27 young cows, and 29 replacement heifers. Average Arkansas cattle quality was assumed to eliminate the impact of modifying herd genetics and attendant price effects for all strategies. Cattle were thus valued using average Arkansas cattle prices for appropriate weight classes and most common quality levels as automatically assigned in FORCAP. All cows and heifers were bred in January of each year. Heifers were bred at 15 months of age as specified in FORCAP. Culling and heifer retention decisions were made in May of each year at the same time calves were weaned and sold. Each year one sixth of the mature cows are culled based upon an expectation of weaning six calves from a cow over their useful lives. The fall calving rate in FORCAP automatically sets a breeding failure rate of six percent along with a one percent cow death loss and three percent calf death loss. The number of replacement heifers needed to maintain the herd size is a function of cull cow sales and death losses. Retention numbers can be manipulated by the user to grow or shrink the herd. A separate model run was performed each year, by herd size, and fertilizer strategy, to assign relevant forage production and price data for that year. Herd size, cull numbers, and heifer retention were modified for the DCA and MA strategies yearly. A total of 198 sets of herd performance statistics was thus collected in FORCAP as a result of annual evaluations of aforementioned scenarios over eleven years.

Prices

Nominal prices were used for hay, feed, fertilizer, fertilizer application costs, winter annual seed, and diesel fuel for the entire period 2004-2014 (Table 1). For fertilizer and fuel prices, data was gathered from NASS (2014) for 2004-2008 and from Mississippi State University (2014) for 2009-2014. Hay and feed prices were gathered for the entire period from NASS (2014). When data was not readily available for these inputs, similar inputs with available price data, were used to create a value for that year. These values were created by adding the intercept coefficient to the substitute variable price multiplied by its variable coefficient. Prices of DAP were regressed against Urea and super-phosphate from 2008 to 2015 to generate the missing value for DAP in 2016.

$$\boldsymbol{P_{DAP}} = \boldsymbol{a_0} + \boldsymbol{a_1 P_{urea}} + \boldsymbol{a_2 P_{super\ phosphate}} + \varepsilon \qquad R^2 = 0.99 \qquad \text{Eq. 1}$$

where P_{DAP} is the price in \$/ton of diammonium phosphate (18-46-0), P_{urea} is the price of urea (46-0-0), $P_{super\ phosphate}$ is the price for phosphate fertilizer (0-45-0), a_0 is the constant term, and ε is the error term.

By the same token, the price of ammonium nitrate was regressed against the price of urea to determine prices for 2014-2016, as follows:

$$\boldsymbol{P_{ammonium\ nitrate} = b_0 + b_1 P_{urea} + \delta} \qquad R^2 = 0.86 \qquad \text{Eq. 2}$$

where $P_{ammonium\ nitrate}$ is the price of ammonium nitrate (34-0-0) in \$/ton, b_0 is the constant term, δ is the error term with the other variable as defined above.

Finally, the price of corn for local feed grain as sourced from Feedstuffs (Informa Group, 2017, Kansas City), was regressed against the Arkansas price received (NASS, 2017) for corn to determine feed price for 2004-2008.

$$\boldsymbol{P_{feedstuff} = c_0 + c_1 P_{Arkansas\ corn} + \gamma} \qquad R^2 = 0.96 \qquad \text{Eq.3}$$

where $P_{feedstuff}$ is the price of feed corn as sourced from Feedstuffs in \$/bu, $P_{Arkansas}$ is the price received for Arkansas corn in \$/bu, c_0 is the constant term, and γ is the error term.
A summary of prices used is provided in Table 1.

Herd Size Changes Across Strategies

The steady state strategy is used as the baseline management strategy in this study. In the 100-cow scenarios, 17 cows are culled every year in May and 18 heifers from the prior year's heifer calves are retained as replacement heifers to be bred to maintain the herd size given the expectation of one cow death loss. Likewise, 27 mature cows are culled, 2 cows are expected to die, and 29 heifers are retained in the 160-cow scenarios. This strategy simulates a producer who maintains a constant herd size despite changing weather and cattle prices. This strategy is considered the least management intensive.

The moving average strategy is based upon price signals that are readily available to producers. The starting point for the 100-cow scenario is identical to the steady state strategy with 83 mature cows, 17 young cows, and 18 bred heifers. Heifer retention decisions are decided by the price signal in January of the current year. Historical, ten-month and twenty-seven month moving averages of #4-500 Medium & Large Frame No.1 feeder steer prices are plotted against each other every month as the cycle progresses. This price series was chosen as that category of animal makes up the largest component of farm sales for a cow-calf operation as part of heifer calves are retained and cull cow sales occur at lower prices. Using 10- and 27-month moving average prices to capture changes in long term price trends, the producer reduces herd size (compared to steady state replacement heifer needs) to capture high calf price revenue when the 10-month moving average is above the 27-month moving average by selling an extra two replacement heifers in anticipation of eventual downward pressure on prices. The 27-month period was chosen as a heifer bred for the first time at 15 months of age would have calved at 2 years of age and would be ready for a second breeding at 27 months of age and hence signals a herd expansion or liquidation time. The shorter-term, 10 month, average captures the time from when the bull is added to the cows in January until calving in October with an average one-month period for breeding. Herd size expansion occurs in years where a downward trend is observed as retaining more heifers also sacrifices lesser sales revenue compared to when price is trending up and because an eventual upward pressure on prices is anticipated. The same signal was used for the 160-cow scenarios except that the number of added or fewer replacement heifers retained or sold increased from two to three. Using a larger increment or decrement for extra heifers to retain when compared to the steady state strategy was not undertaken as herd sire needs would change.

The dollar cost averaging strategy uses constant yearly reinvestment in the herd. Nominal prices were used for this strategy to simulate how producers react to the marketplace. Yearly herd reinvestment was determined by finding the value of an 800 pound heifer in the herd size adjustment month of May (Eq. 4) and multiplying by the number needed based on herd size (Eq.5). These values were then averaged across the full cycle (2004-2014) to find the target constant yearly average reinvestment (Eq. 6) needed to determine the annual number of replacement heifers to retain given that year's replacement heifer value (Eq. 7) as follows:

$$\boldsymbol{P_{RH,i} = P_{\#7-800\ heifer,i} * 8} \quad \text{Eq. 4}$$

$$\boldsymbol{R_i = P_{RH,i}} \cdot \begin{cases} \mathbf{18}\ \forall \text{ 100-cow scenarios} \\ \mathbf{27}\ \forall \text{ 160-cow scenarios} \end{cases} \quad \text{Eq. 5}$$

$$\boldsymbol{\bar{R} = \sum_{i=2004}^{2014} R_i / 11} \quad \text{Eq. 6}$$

$$\boldsymbol{Q_{RH,i} = \bar{R} / P_{RH,i}} \quad \text{rounded to nearest head} \quad \text{Eq. 7}$$

where i represents a year in the 2004-2014 cattle cycle, $P_{RH,i}$ is the yearly value of a #800 replacement heifer in $/head, $P_{\#7\text{-}800\ heifer,i}$ is the price in $/cwt of a #7-800 heifer, R_i represents the value of replacement heifers given a 100-cow or 160-cow scenario, $\bar{R}$ is the average yearly reinvestment (2004-2014), and $Q_{RH,i}$ is the annual number of heifers retained.

Analysis

Risk was analyzed using standard deviation and the minimum and maximum of annual cash operating profits by strategy and scenario. Aside from cash operating profits, results also convey the number of bales of hay and cattle sold to provide insight about source of revenue for a scenario by strategy combination. The net present value (NPV) of annual cash operating profits across the entire cattle cycle was calculated to account for time value of money and risk using a discount rate of 5% (Hardie, 1984). Finally, cumulative probability density functions (CDF) of annual estimated cash operating profit data were created for scenarios that did not account for weather but differed by herd size management strategy and for scenarios including weather effects. Following Schlaifer's (1959) approach, observations of cash operating profit by strategy were sorted from smallest to largest across herd size and fertilizer scenarios and plotted to represent 90% of possible profitability outcomes. CDFs of cash operating profitability of the three herd size management strategies could thus be compared, with and without weather risk, where each strategy included 33 annual observations as a result of 11 years of performance data for 100- and 160-cow herd sizes with different fertilizer strategies.

Results

Table 2 shows details of calculations needed to determine herd size changes using the dollar cost averaging (DCA) strategy. Resultant breeding herd sizes and cull cow numbers, that are one or two head fewer than replacement heifer needs given death losses across herd sizes analyzed, are shown in Figure 5 across all strategy (Steady State – SS, Moving Average Price Ratio (MA) and DCA) by scenario (herd size and fertilizer level) combinations.

Under the DCA strategy with 100 cows, the productive herd reached a peak of 113 cows in 2010 and 2011, and a minimum of 100 cows in 2004 as shown in Figure 5. Under the 160-cow scenario, DCA had a peak productive herd of 179 in 2010 and 2011 with the minimum of 160 occurring in 2004. This strategy produced the largest variation with a maximum of 22 and 36 heifers retained in 2009 and a minimum of 11 and 19 retained in 2014 for the 100-cow and 160-cow scenarios respectively. As the herd grew, the number of cows culled per year varied as shown in Figure 5.

The moving average (MA) strategy created three years of herd reduction followed by four years of expansion before reverting back to three more years of reduction to end the cycle. This resulted in ending herd sizes of 99 and 157 cows respectively. The MA strategy generated a maximum productive herd of 106 and 167 in 2010 with minimums of 96 and 153 occurring in 2007 for the different 100- and 160-cow herd size scenarios, respectively (Figure 5).

Both the MA and DCA strategies created variability in herd sizes as a function of changing prices over the cattle cycle. Both strategies moved in the same direction for most of the observed period, but the DCA strategy had much larger variation as shown in Figure 5. Maintaining average yearly investment over time, the DCA strategy led to a larger herd throughout the cycle compared to the SS and MA strategies.

Comparisons of these alternative herd size management strategies are summarized in Table 3 by providing information about cash operating profits as well as quantity of hay and cattle sold. The table provides key performance statistics for all 18 scenario by strategy combinations with and without weather effects. Main comparisons are conducted by column in Table 3 across strategies by scenario and also with and without weather effects.

The DCA strategy always yielded the lowest hay sold and the highest number of head sold as this strategy had the largest herd size throughout. The strategy achieved the goal of selling more cattle during the period of high prices, but much lower hay sales and higher hay purchases offset these profits. Even though management intensity increased compared to SS, the DCA strategy yielded the lowest average return in four of six possible strategy comparisons across three scenarios with and without weather as well as the lowest NPV for all comparisons (Table 3). The lowest NPV numbers are likely a function of the timing of cash flows being the largest in the latter portion of the cycle. The large fluctuations in heifer retention also created the most risk of any of the three strategies. The DCA strategy always had the largest range in cash operating profits.

The MA strategy generated the highest average cash operating profit in four of six comparisons but by a very small margin over the SS strategy (Table 3). In the four comparisons where MA yielded the highest average cash operating profit, the average margin across comparisons was $216.55 over the next best strategy. This represents a gain of 0.96% on average. In three of those four comparisons, the SS strategy yielded the second best profitability performance.

The SS strategy yielded the largest cash operating profit in only one scenario but created a more stable cash flow as evidenced in relatively low range in cash operating profits across all strategy by scenario and weather effects combinations. This strategy sold the fewest head and the most hay.

Figure 6 provides a visual analysis of cash operating returns across varying herd size and fertilizer management options by herd size management strategy without weather effects by plotting the likelihood of achieving a particular profitability level across the eleven study years. As in Table 3, the CDFs demonstrates that herd size management strategy had small implications on cash operating profit across a wide array of farm management options. Nonetheless, small marginal gains in cash operating profit were generated by the MA strategy. The SS strategy is the most profitable option for the majority of the bottom half of the CDF [Figure 6 (1)]. The DCA strategy is the best option for the upper 10% of the CDF, but only by a small margin.

Figure 7 shows the same cumulative distribution function but for scenarios with weather risk. With weather risk, there is more variation in returns, but the results are very similar to the previous graph (Figure 6). SS is the best strategy along the bottom half of the CDF [Figure 7(1)], while DCA is the best along the top third [Figure 7(2)]. Once again the margins are small, but MA is almost always the second best scenario. Figure 8 shows the MA and SS strategies with and without weather variability. This graph shows that weather risk created larger cash operating profits on average [Figure 8(1)] without significantly increasing risk (CDFs are not flatter with weather risk). The DCA strategy was not included as it ranked poorest in Figures 6 and 7. Also comparisons between the two most viable strategies, SS and MA, were less cluttered.

Conclusion

The aforementioned scenarios use a fixed land base but encompass a variety of production decisions such as fertilizer application rates and stocking rates as endogenous variables, as well as weather risk as an exogenous variable. As shown above, all the strategies have the potential to yield the highest average cash operating profits with the given parameters when comparing across all scenarios. The MA strategy shows that heifer retention based upon a market signal can consistently generate a slightly higher profit margin for a variety of operations and real world weather conditions, but this margin is very small, approximately 1%. Both the MA and DCA strategies are more data intensive and thereby require more management than the SS strategy. In addition, these two strategies are more risky in terms of cash operating profit variability. For many producers, this marginal higher return will not be enough to compensate for the added risk and time needed for management in this author's opinion. If a producer is risk seeking and looking for the highest possible return, the DCA strategy showed the potential for highest cash operating profits at the upper end of the cumulative profitability density functions.

By increasing stocking rates and fertilizer application rates, producers are able to increase cash operating profits, but these management decisions did not affect the outcome of herd size management strategy selection (Table 3). Over the last cattle cycle, 2004-2014, a steady state strategy for herd management is likely the most viable option for the majority of producers. This strategy balances profitability with risk and time devoted to size management.

This research was designed to test whether heifer retention strategies based upon market price signals would create larger cash operating profits in cow-calf operations. This hypothesis was based upon Lawrence's 2002 research. Using a fixed land base, weather variability, and hay sales, our research showed that a DCA strategy is not more profitable on average in northwest Arkansas than a SS strategy. A MA strategy was shown to be slightly more profitable than SS, but this small margin was not deemed adequate to offset greater risk and needed additional management to execute this strategy for most producers.

While this research did examine various management decisions related to fertilizer application and stocking rates, it was limited by a land resource. With a much larger land resource and subsequently larger herd sizes, marginal gains by market signal strategies could be large enough to warrant widespread adoption. In addition, this research only examined the 2004-2014 cattle cycle. In a BEEF magazine article, Harlan Hughes argues that this cattle cycle is not a true representative cycle due to policy variables such as the ethanol mandate and the enormous drought that affected much of the country in 2011-2012. Hughes predicts that in past cycles and possibly future cycles, heifer retention strategies that vary based upon market signals, are more profitable than a steady state strategy (Hughes, 2017). Further research should be conducted to determine the validity of this prediction. Finally, a 10- and 27-month moving average price ratio was used to signal price trend changes. Different-length moving average prices may lead to different outcomes.

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Table 1. Summary of Nominal Price Information Used for Cattle, Hay, and Input Prices, 2004 – 2014, Arkansas.

		Unit	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fertilizers	Lime	ton	21	21	22	23	26	28	25	36	34	35	38
	Amm. Nitrate	ton	263	292	366	382	509	560	285	360	411	450	413
	DAP	ton	276	303	337	442	850	960	328	500	649	640	515
	Potash	ton	181	245	273	280	561	880	522	460	584	596	475
	Urea	ton	276	332	362	453	552	540	326	380	446	568	452
	Poultry Litter	ton	23	23	23	23	23	23	23	23	23	23	23
Seed	Ryegrass	cwt	53	59	70	72	79	79	70	73	95	100	101
	Winter Wheat	cwt	14	15	16	18	25	27	23	26	29	30	31
Fuel	Diesel	gal	1.63	1.74	1.76	1.75	1.98	2.16	1.52	1.24	1.72	1.87	1.86
Feed	Corn	bu	1.94	1.65	2.34	3.62	4.36	3.64	4.18	6.83	6.88	5.64	4.10
	Hay	ton	48	64	84	90	87	74	80	101	132	128	115
Steer Calves	#4-500	cwt	121	130	129	122	113	108	123	148	175	176	255
	#5-600	cwt	111	118	118	113	105	100	115	139	159	159	230
	#6-700	cwt	104	112	109	107	99	94	108	131	147	147	210
	#7-800	cwt	98	106	102	101	95	90	103	125	139	139	197
Heifer Calves	#4-500	cwt	111	120	115	108	98	93	108	130	153	156	229
	#5-600	cwt	104	112	107	102	94	89	103	124	142	144	209
	#6-700	cwt	98	105	101	98	90	86	98	119	134	135	194
	#7-800	cwt	92	99	95	94	88	83	95	114	126	127	181
Culls	Cows	cwt	49	51	46	48	49	44	53	66	76	76	100
	Bulls	cwt	63	64	57	59	62	55	65	79	92	94	119

Table 2. Dollar Cost Averaging Summary for 100-Cow and 160-Cow Scenarios.

Year (i)[†]	#7-800 Medium & Large Frame No. 1 Heifers in $/cwt ($P_{RH,i}$)[‡]	Average Yearly Reinvestment ($\bar{R}$)[§]	Heifers Retained[¶,#] (100-Cow) ($Q_{RH,i}$)	Heifers Retained[¶,#] (160-Cow) ($Q_{RH,i}$)
2004	93		21	34
2005	102.57		19	31
2006	93.78	$15,720.55 (for 100 cows)	21	34
2007	97.81		20	32
2008	95.22		21	33
2009	87.37		22	36
2010	97.46		20	32
2011	113.44	$ 25,327.55 (for 160 cows)	17	28
2012	132.53		15	24
2013	120.61		16	26
2014	167.11		12	19

Notes: Unit Conversion 1 cwt = 100 lbs = 45.36 kg.

† Year *i* denotes a year in the 2004-14 cattle cycle.

‡ Price of replacement heifers is multiplied by 8 cwt to arrive at the average value of a replacement heifer as in Eq. x using May as the time when cull cows are sold and bred replacement heifers enter the herd as young cows.

§ Average annual investment over the cattle cycle using a steady state replacement strategy of 18 heifers for 100-cow operations and 27 heifers for the 160-cow operations as in Eq. y.

¶ Number of replacement heifers retained to modify herd size with the dollar cost averaging strategy. The number of heifers is rounded to the nearest head using Eq. z.

\# Steady state strategy is to retain 18 or 27 replacement heifers each year to account for 1 or 2 death loss(es) and 17 or 25 cull cows for the 100- and 160-cow operations, respectively.

Table 3. Profitability Statistics for All Scenarios and Strategies (2004-2014).

		Scenario[†]							
# of cows bred annually		100			100		160		
Fertilizer applied		Low			Med		High		
Strategy[‡]	Performance Statistics	Net Cash Returns[§]	Hay Sold[§]	Head Sold[§]	Net Cash Returns	Hay Sold	Net Cash Returns	Hay Sold	Head Sold
SS	Avg. [¶]	20,552	49	90	22,967	171	25,444	46	146
	Std. Dev. [¶]	13,777	0	0	15,096	0	22,635	0	0
	Min.[¶]	4,071			5,223		-3,869		
	Max.[¶]	53,185			57,376		78,610		
	NPV[¶]	160,231			178,257		194,979		
MA	Avg.	**20,637**[#]	28	92	23,249	152	**25,819**	44	147
	Std. Dev.	15,207	41	4	16,429	35	24,732	50	6
	Min.	1,548			3,153		-6,815		
	Max.	55,662			59,652		82,214		
	NPV	160,757			180,206		197,643		
DCA	Avg.	20,111	-47[‡‡]	98	23,283	84	25,179	-76	157
	Std. Dev.	17,414	50	6	18,609	47	27,735	75	8
	Min.	376			2,455		-8,511		
	Max.	61,826			66,076		91,417		
	NPV	153,491			177,633		188,563		
SS+[††]	Avg.	20,820	40	90	23,654	171	**26,966**	62	146
	Std. Dev.	14,394	106	0	15,582	104	23,133	147	0
	Min.	5,717			6,441		-581		
	Max.	53,097			57,014		81,802		
	NPV	159,415			181,196		203,544		
MA+	Avg.	**21,093**	21	92	**23,858**	151	26,826	48	147
	Std. Dev.	15,625	98	4	16,592	93	24,550	142	6
	Min.	3,858			5,286		-3,699		
	Max.	55,577			59,363		83,401		
	NPV	161,360			182,835		201,970		
DCA+	Avg.	20,546	-56	98	23,725	78	26,296	-72	157
	Std. Dev.	18,181	82	6	19,088	76	28,062	120	8
	Min.	1,454			4,626		-4,484		
	Max.	61,808			65,724		94,015		
	NPV	153,780			178,564		193,459		

Notes: Unit Conversions 1 lb = 0.4536 kg. 1 acre = 0.4711 hectare. 1 ton = 907.2 kg

[†] Scenarios are defined by number of cows bred as of the first year of the cattle cycle as well as the level of fertility on hay and pasture land pursued. Low fertilizer = (on hay: 0.25 ton/acre of lime, 100lbs/acre of ammonium nitrate, and 2 tons/acre of poultry litter; on pasture: 0.25 ton/acre of lime and 0.5 ton/acre of poultry litter). Med fertilizer = (on hay: 0.25 ton/acre of lime, 100lbs/acre of ammonium nitrate, and 2 tons/acre of poultry litter; on pasture: 0.25 ton/acre of lime and 1 ton/acre of poultry litter). High fertilizer = (on hay: 0.25 tons/acre of lime, 300 pounds/acre of ammonium nitrate, 3 tons/acre poultry litter; on pasture: 0.25 tons/acre of lime, 100 pounds/acre of ammonium nitrate, 2 tons/acre poultry litter). Scenarios are

further differentiated by the absence (top half) or presence (bottom half) of weather driven changes in forage production.

‡ SS = Steady state cow herd size, MA is a cow herd size strategy using a ratio of two moving averages of feeder steer prices to signal an up- or downtrend in cattle prices. DCA is the dollar cost averaging strategy as described in Table 2 and Eqs. 4 – 7.

§ Net Cash Returns (NCR) are cash operating profits resulting from sale of cattle and excess hay after accounting for feed and supplements, seed, fuel, fertilizer, twine, chemicals, veterinary services, operating interest, repairs and medicine in $/year. Capital ownership charges including depreciation, insurance, taxes and opportunity cost of capital are excluded. Hay sold is the number of #1,200 round bales. Head sold represents the number of cull animals as well as weaned calves sold during a marketing year.

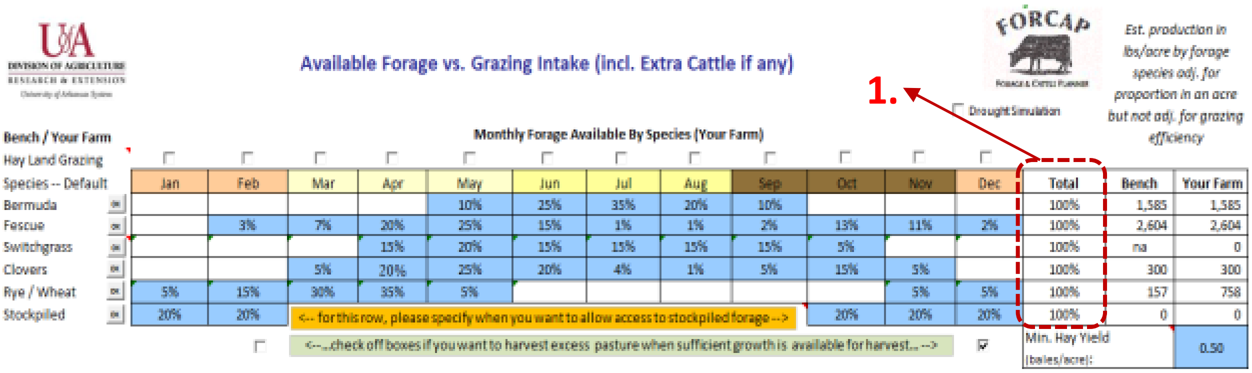
¶ Avg. and Std. Dev. represent the average and standard deviation of annual NCR across the 2004-2014 cattle cycle. Min and Max represent the range of observed values and NPV is the net present value of net cash returns $NPV = \sum_{i=2004}^{2014} \frac{NCR_i}{(1+k)^{i-2003}}$ where k is the discount rate accounting for inflation and risk. 5% was chosen in this study and represents a mid-range value common for agricultural studies (Hardie, 1984).

Bold face indicates highest avg. and NPV performance measure for a particular scenario across strategies.

†† SS+, MA+ and DCA+ indicate the addition of weather effects on forage availablility. Climate was modeled by calculating a production index as shown in Eq. x. NDVI indeces over time were used to compare monthly values to longer-term averages for that month to determine whether production was more or less than long-term average.

‡‡ Negative hay numbers indicate on average hay was bought off farm.

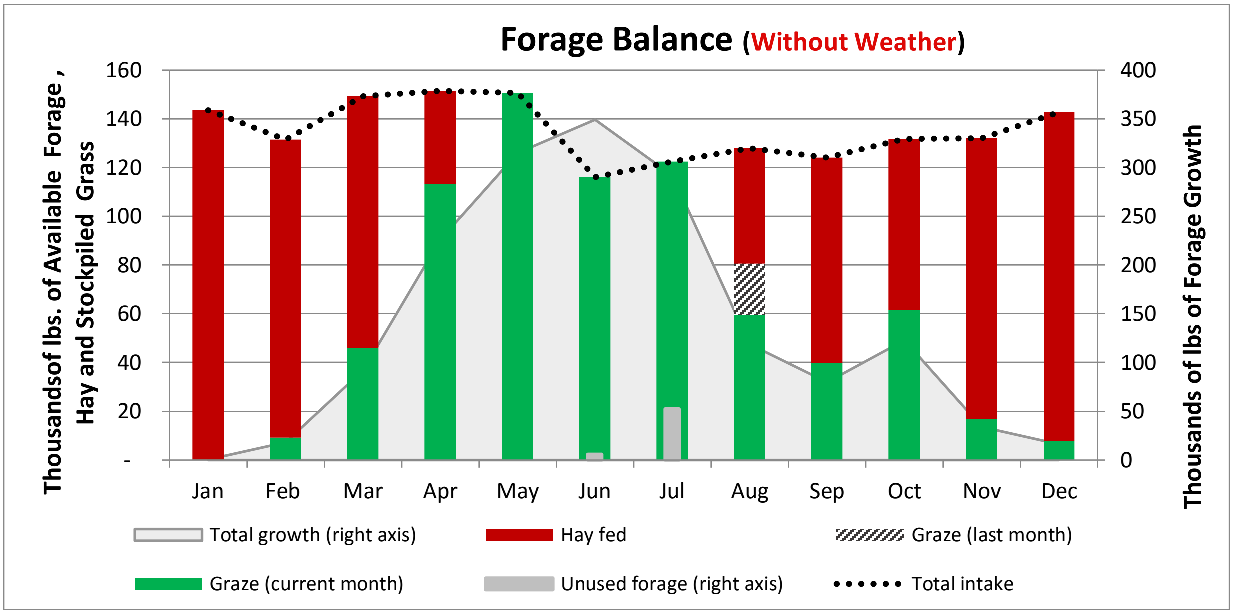
Figure 1. Forage Balance without Weather Variability (from Forage and Cattle Analysis and Planning (FORCAP))



Species -- Default	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Bench	Your Farm
Bermuda					10%	25%	35%	20%	10%				100%	1,585	1,585
Fescue		3%	7%	20%	25%	15%	1%	1%	2%	13%	11%	2%	100%	2,604	2,604
Switchgrass				15%	20%	15%	15%	15%	15%	5%			100%	na	0
Clovers			5%	20%	25%	20%	4%	1%	5%	15%	5%		100%	300	300
Rye / Wheat	5%	15%	30%	35%	5%						5%	5%	100%	157	758
Stockpiled	20%	20%	<-- for this row, please specify when you want to allow access to stockpiled forage -->							20%	20%	20%	100%	0	0

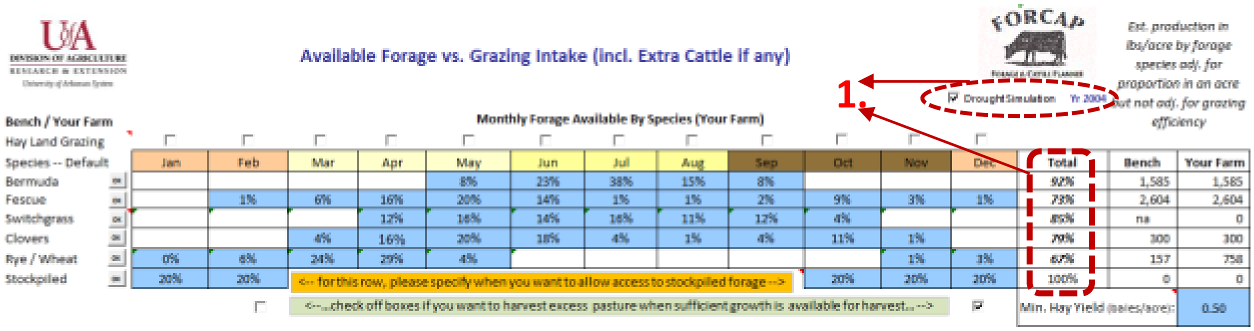
<--...check off boxes if you want to harvest excess pasture when sufficient growth is available for harvest... -->

Min. Hay Yield (bales/acre): 0.50

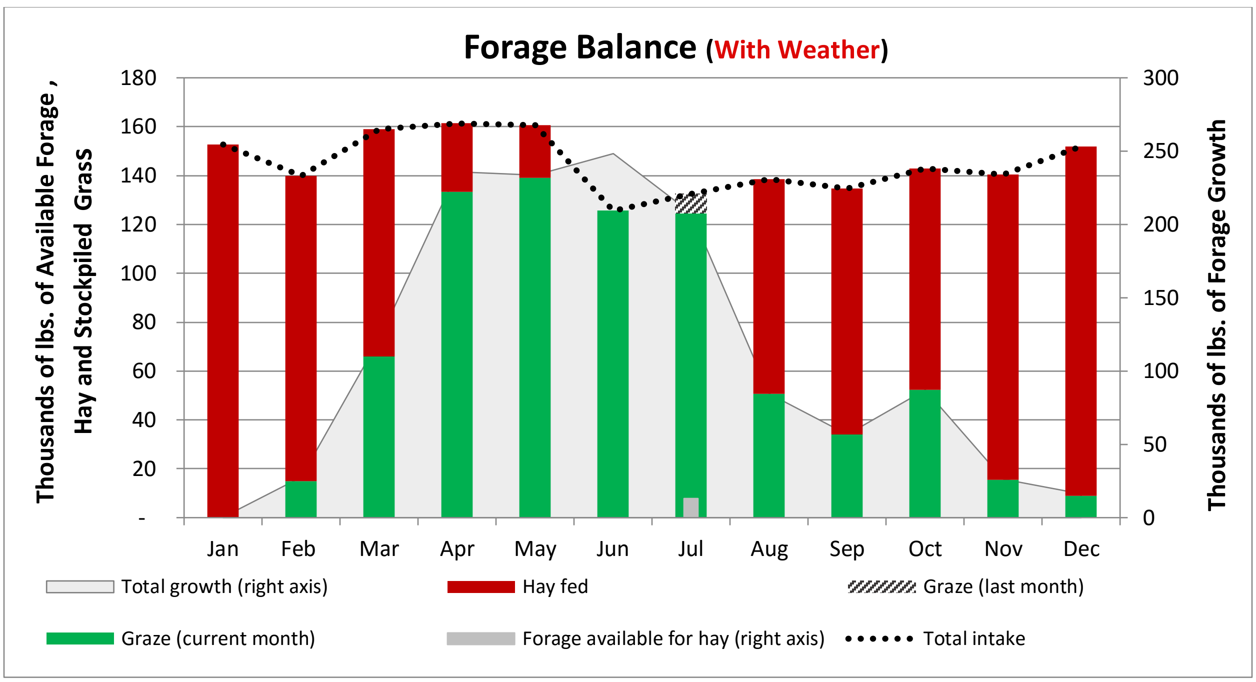


Note: (1) Without weather variability, forage yields are set at a baseline and remain constant year-to-year. Unit Conversions 1 lb = 0.4536 kg. 1 acre = 0.4711 hectare.

Figure 2. Forage Balance with Weather Variability (from Forage and Cattle Analysis and Planning (FORCAP))



Species -- Default	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Bench	Your Farm
Bermuda					8%	23%	38%	15%	8%				92%	1,585	1,585
Fescue		1%	6%	16%	20%	14%	1%	1%	2%	9%	3%	1%	73%	2,604	2,604
Switchgrass				12%	16%	14%	16%	11%	12%	4%			85%	na	0
Clovers			4%	16%	20%	18%	4%	1%	4%	11%	1%		79%	300	300
Rye / Wheat	0%	6%	24%	29%	4%						1%	3%	67%	157	758
Stockpiled	20%	20%								20%	20%	20%	100%	0	0



Note: (1) With the Drought Simulation box checked, forage yields are adjusted to the specified year based on satellite imagery. Yields for forages can be above or below 100%. Unit Conversions 1 lb = 0.4536 kg. 1 acre = 0.4711 hectare.

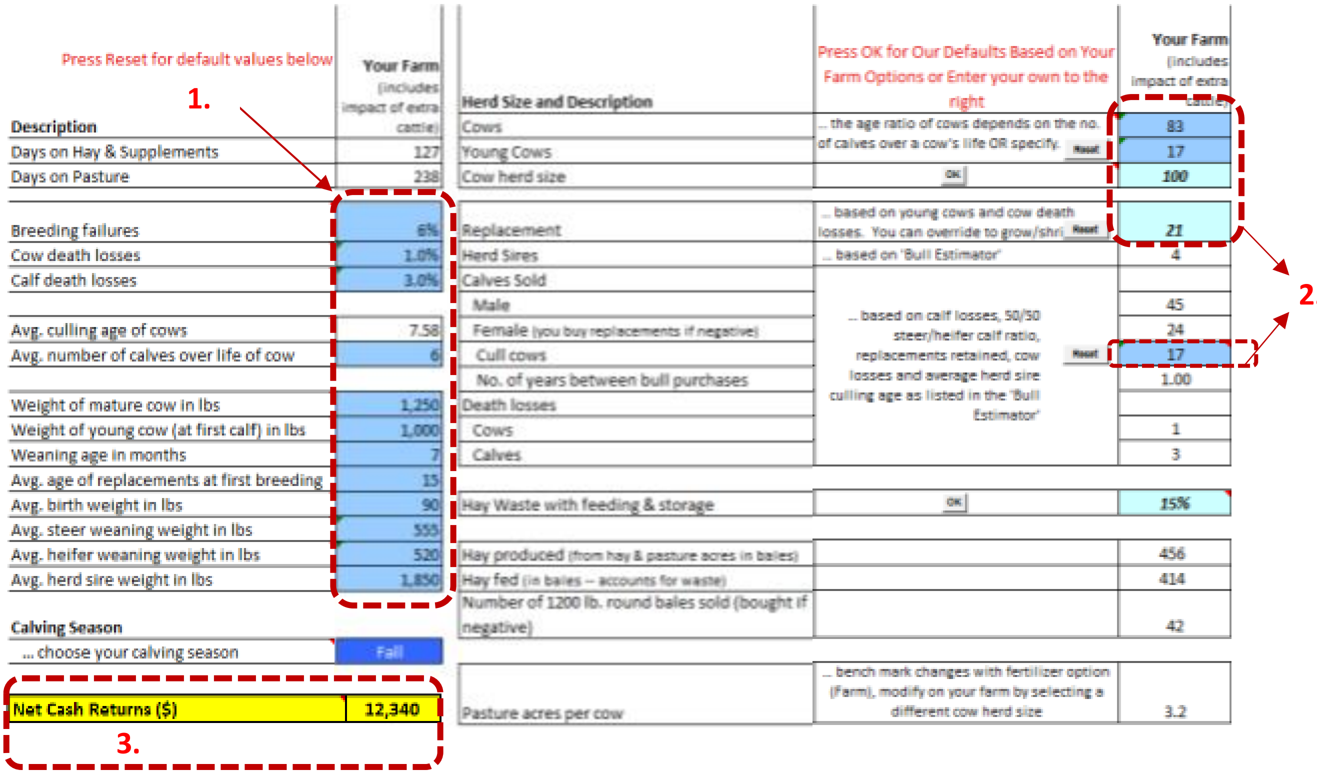
Figure 3. Winter Annual Forage Production Option and Forage Species Mix (adapted from Forage and Cattle Analysis and Planning (FORCAP) with Benchmark Farm Option Removed.

				Available	Acres
1.	Do you plant a winter annual...?	*Wheat*	☑	*80*	80
	Do you practice stock piling ...?		☐	*160*	30
	Do you practice strip grazing... ?		☐		

	Forage Species Composition...	Bermuda	Fescue	Clover	**Total**	Hay Yield (in Bales per Acre)
2.	... on hay land	50%	45%	5%	**100%**	4.0 3.
	... on pasture land	25%	65%	10%	**100%**	0.4

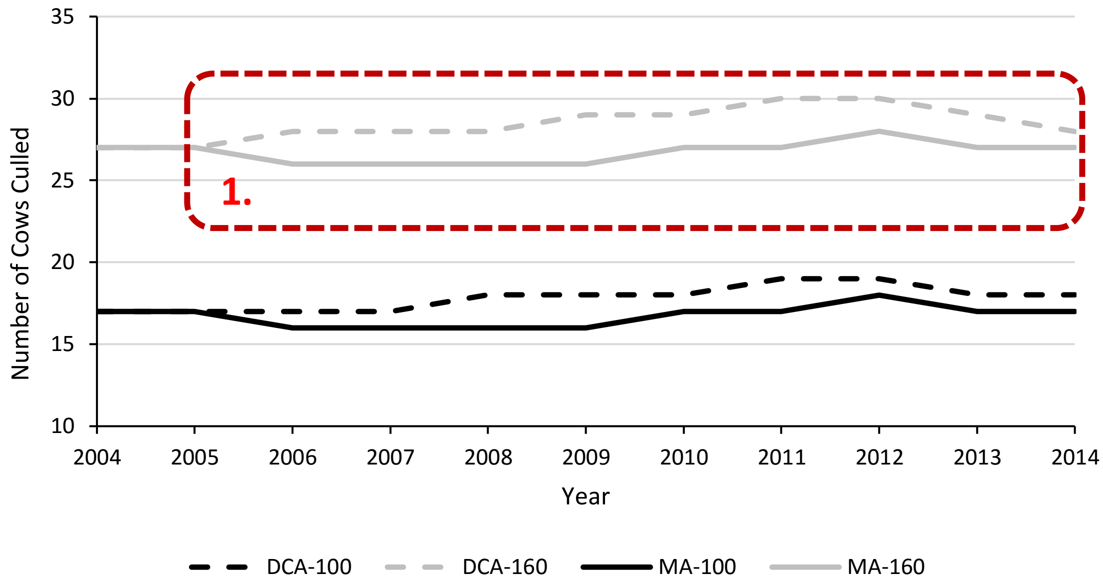
Notes: (1) Winter Annual option is selected as wheat and acres option is set at maximum of 80 acres. (2) Forage Species Composition varies between pasture and hay acreage (3) Hay yield in #1,200 bales differs largely between hay and pasture acres due to pasture acres being grazed by cattle and only being harvested when sufficient excess forage is present. Unit Conversions 1 lb = 0.4536 kg. 1 acre = 0.4711 hectare.

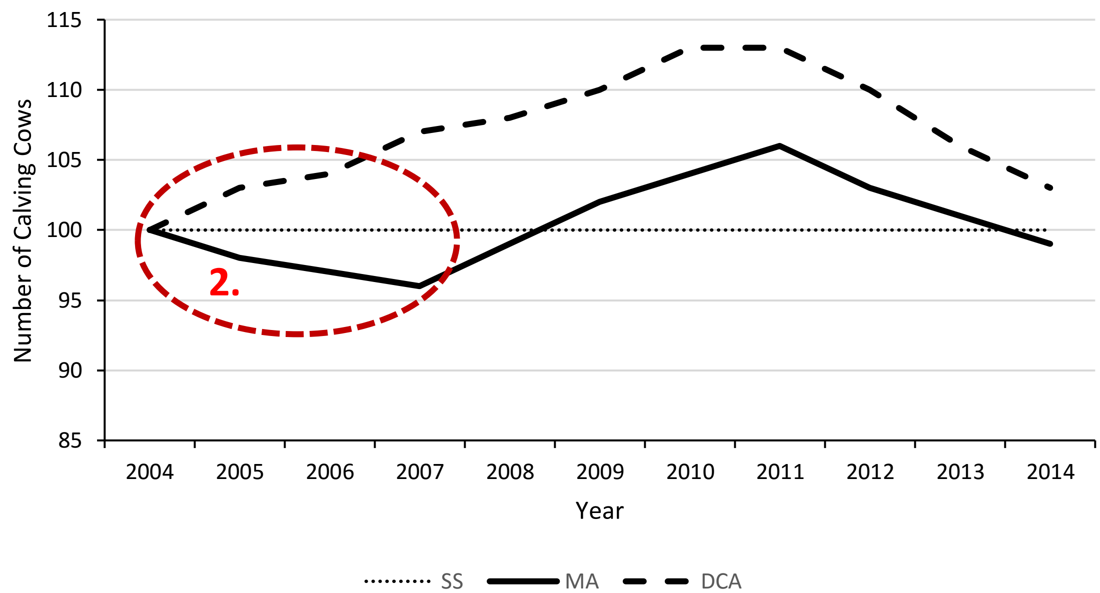
Figure 4. FORCAP Cattle Specifications (adapted from Forage and Cattle Analysis and Planning (FORCAP) with Benchmark Farm Option Removed).



Note: (1) Birth Weight, Weaning Weight, Death Loss, etc. are automatically specified in the model. (2) Cattle herd makeup, number of heifers retained, and number of mature cows culled can be modified yearly. (3) Production decision effects on net cash returns can be evaluated. Unit Conversions 1 lb = 0.4536 kg. 1 acre = 0.4711 hectare.

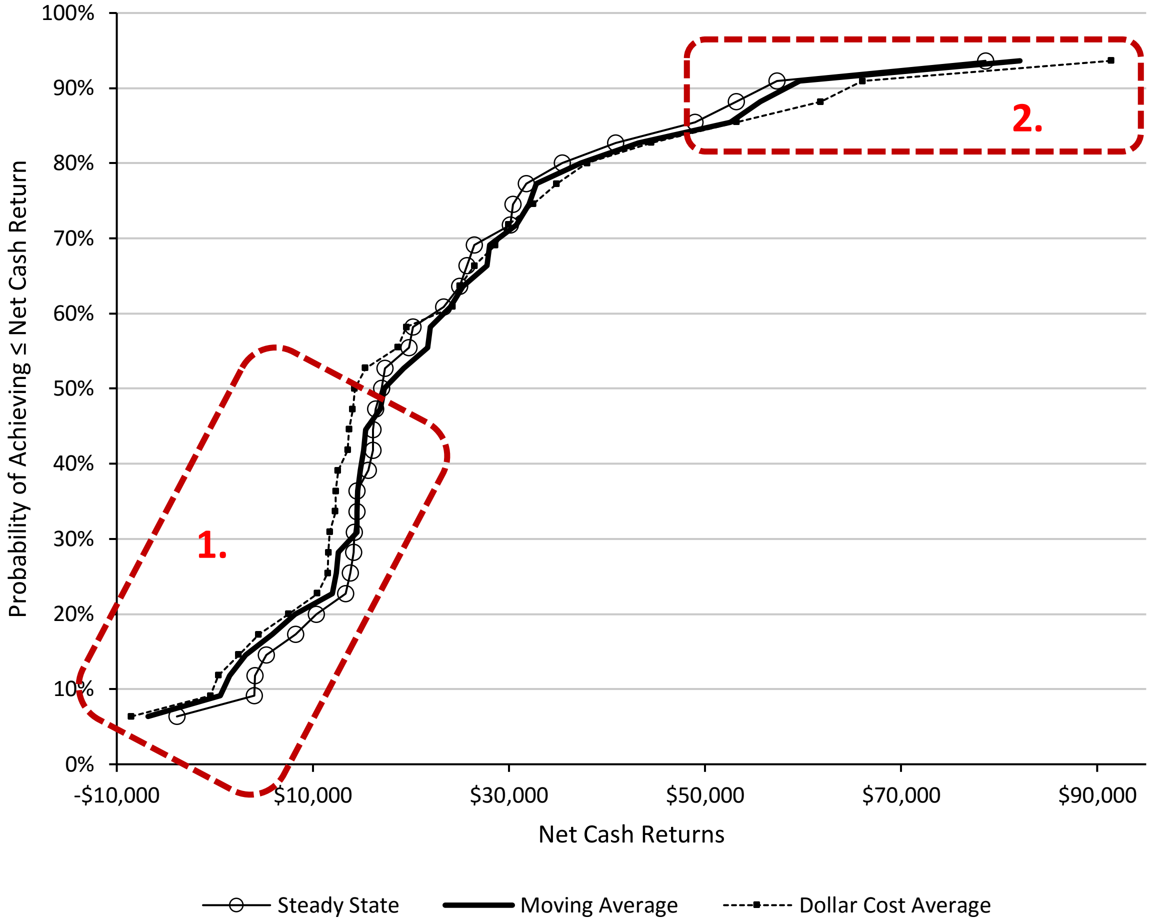
Figure 5. Variation of Yearly Cull Cows Across Strategies and Scenarios and Calving Cow Herd Size for the 100-Cow Scenarios.





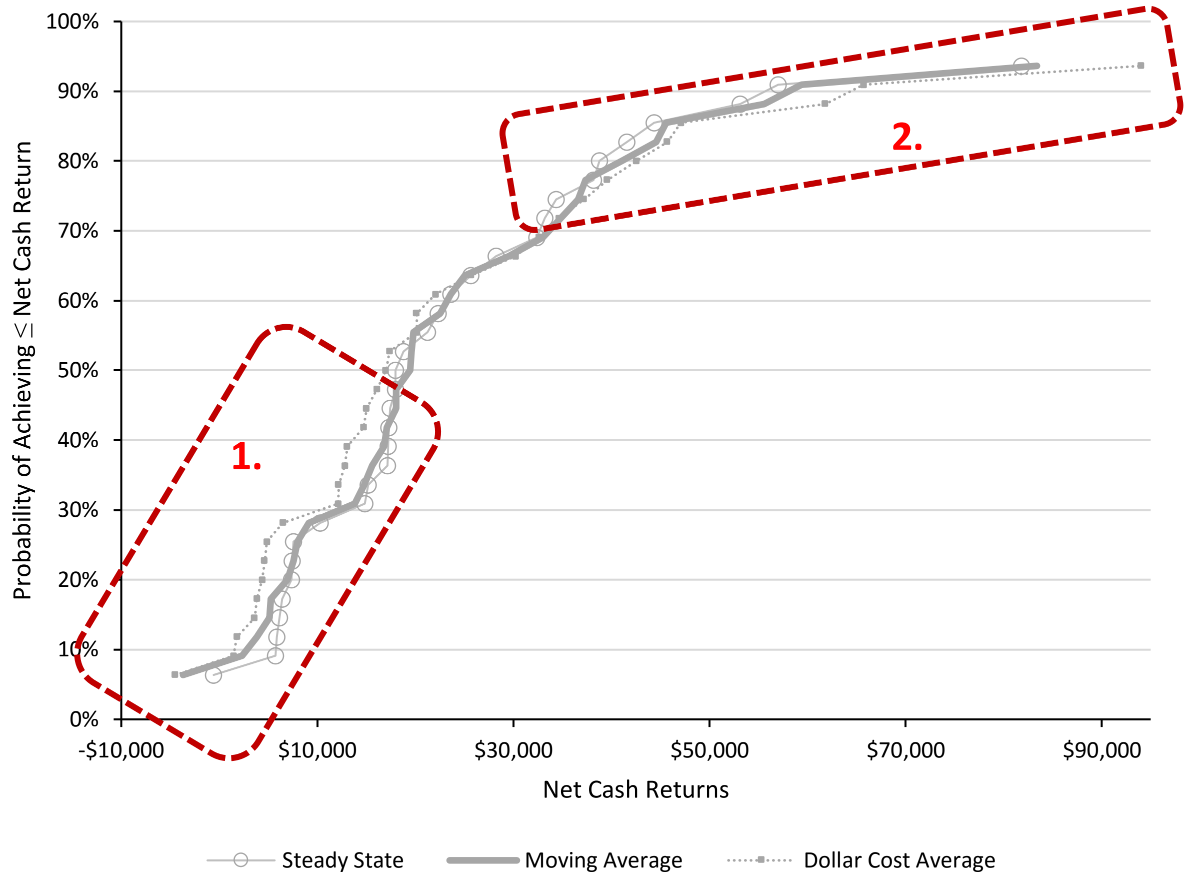
Note: SS = Steady state cow herd size, MA is a cow herd size strategy using a ratio of two moving averages of feeder steer prices to signal an up- or downtrend in cattle prices. DCA is the dollar cost averaging strategy as described in Table 2 and Eqs. 4 – 7. (1) Yearly cull numbers increase in relation to magnitude of herd expansion by Dollar Cost Averaging or Moving Average strategies. (2) Divergence between DCA and MA strategies can be seen from 2004-2007. 160-cow herd numbers are not shown as same trends are evident.

Figure 6. Cumulative Probability Density Functions (CDFs) of Cash Operating Profit by Herd Size Management Strategy without Weather Effects.



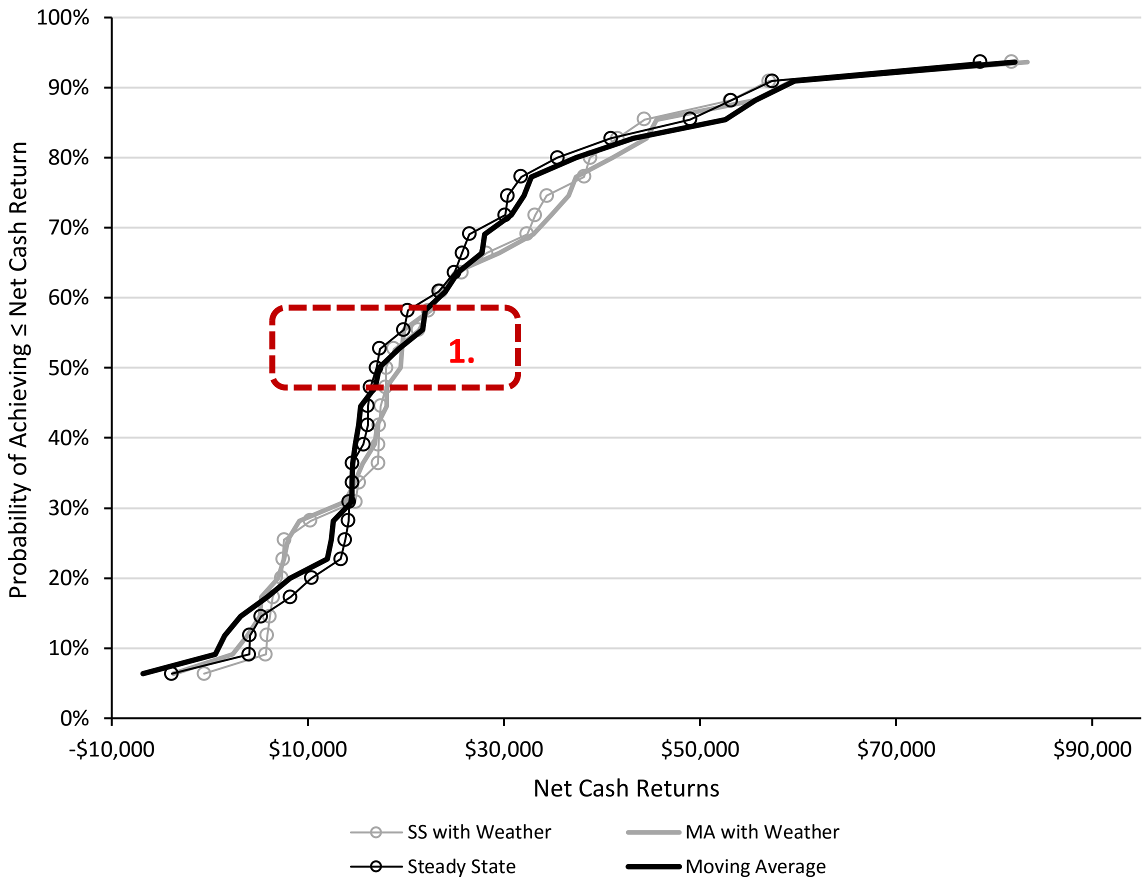
Note: SS = Steady state cow herd size, MA is a cow herd size strategy using a ratio of two moving averages of feeder steer prices to signal an up- or downtrend in cattle prices. DCA is the dollar cost averaging strategy as described in Table 2 and Eqs. 4 – 7. Net Cash Returns (NCR) are cash operating profits for the ranch resulting from sale of cattle and excess hay after accounting for feed and supplements, seed, fuel, fertilizer, twine, chemicals, veterinary services, operating interest, repairs and medicine. (1) bottom half of CDF (2) highlights upper 15% of CDF.

Figure 7. Cumulative Probability Density Functions of Net Cash Returns by Herd Size Management Strategy with Weather Effects.



Note: SS = Steady state cow herd size, MA is a cow herd size strategy using a ratio of two moving averages of feeder steer prices to signal an up- or downtrend in cattle prices. DCA is the dollar cost averaging strategy as described in Table 2 and Eqs. 4 – 7. Net Cash Returns (NCR) are cash operating profits for the ranch resulting from sale of cattle and excess hay after accounting for feed and supplements, seed, fuel, fertilizer, twine, chemicals, veterinary services, operating interest, repairs and medicine. (1) bottom half of CDF (2) highlights upper 15% of CDF.

Figure 8. Combined Cumulative Probability Density Functions of Net Cash Returns by Steady State and Moving Average Strategies With and Without Weather Effects.



Note: SS = Steady state cow herd size, MA is a cow herd size strategy using a ratio of two moving averages of feeder steer prices to signal an up- or downtrend in cattle prices. Net Cash Returns (NCR) are cash operating profits resulting for the ranch from sale of cattle and excess hay after accounting for feed and supplements, seed, fuel, fertilizer, twine, chemicals, veterinary services, operating interest, repairs and medicine. (1) highlights the 50% (average) mark.