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Evaluating the Cost of Gain and Financial Returns of Cattle Fed Hydroponically Produced Barley Fodder

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Abstract

Hydroponically produced fodder continues to garner attention as a feed source within livestock production. This attention in part is due to a belief that hydroponically produced fodder is more efficient in its use of inputs such as water when compared to conventional feeds. Water efficiency is especially appealing in areas like the Intermountain West region of the U.S where water availability is often constrained. This analysis looks to understand how using hydroponically produced barley fodder to finish steers compares economically to finishing steers on a nutritionally equivalent conventional finishing ration. To do so, a stochastic simulation model is constructed to compare the expected cost of gain and net return per head when finishing steers on a conventional ration and hydroponically produced barley fodder ration. The simulation results suggest that finishing steers on a hydroponically produced barley fodder ration leads to a mean cost of gain $0.25 higher than a conventionally fed steer's cost of gain, and a mean net return per head $88 lower than the conventional mean net return per head. Using a sensitivity analysis to better understand these results, we find that using hydroponically produced barley fodder to finish steers becomes more financially feasible than conventionally finished steers only when conventional feed prices are pushed to unrealistic extremes.

Introduction

Hydroponically produced fodder is considered a feed substitute to more conventional feed ration components and often viewed as a potential solution to mitigate risks such as drought to livestock producers (Sneath and McIntosh, 2003). Hydroponic production systems can mitigate drought risk as they are capable of recycling water while producing large feed quantities. This ability to produce feed regardless of drought conditions may be especially attractive to livestock producers in the high desert landscape of the Mountain West region where annual precipitation is limited and melting snowpack and reservoirs are relied upon for feed production throughout the growing season. Utah State University partnered with a Utah-based company, Renaissance Ag, to evaluate the potential use of their hydroponic barley sprout production system in the Intermountain West region. Multiple studies were conducted during this partnership to analyze both the biological and financial impacts of these systems across various livestock industries including dairy, sheep, and beef cow/calf production. This current analysis evaluates the financial feasibility of using hydroponically produced barley fodder to finish beef steers in the Intermountain West region using a stochastic simulation model. Specifically, this analysis aims to 1) simulate the expected cost of gain (COG) and net return over feed costs when finishing steers on both a conventional finishing ration and a hydroponic barley fodder-based finishing ration; 2) provide a sensitivity analysis around the expected results to better understand the risk associated with the expected outcomes.

Literature Review

Many studies have been conducted to further the understanding and implementation of hydroponic systems in livestock production. Most of these studies have focused on the economic and biological outcomes. A study conducted in 2022 to evaluate the production and costs between conventional feed production and hydroponic fodder production on a square meter basis found that hydroponic fodder production does conserve significant amounts of water with conventional feed production using sprinklers for irrigation requiring three times more water to produce the same amount of dry matter feed. Despite the water savings found in the study, the same study also found that the costs associated with fodder production led to a loss of $0.31 per square meter while conventional production led to a gain of $0.19 per square meter (Elmulthum et al., 2023). This study, however, did not consider the water required to produce the seed used to grow the fodder in the hydroponic system.

An analysis conducted by Daniel Putnam and Peter Robinson at the University of California in 2016 looked at prior water conservation studies comparing hydroponic fodder and conventional feed. In this analysis, they found that the water usage in a hydroponic fodder production system is greater than conventional feed production per unit when the water needed to produce the seeds is included in the overall water consumption of the fodder production. This analysis also acknowledges that hydroponic fodder production will save water locally if the seeds are grown elsewhere when compared to conventional production (Putnam and Robinson, 2016).

Soumeya et al. (2016) looked at the costs and effects of feeding hydroponic fodder to dairy cattle. The effect of fodder consumption on milk production was measured in both quality and quantity. It was found that both the quantity and quality remained similar between both the test group and control group fed conventional feed. While the researchers considered this evidence that it is an acceptable substitute to conventional feed, they also found that hydroponic fodder production costs four times more than conventionally produced feed (Soumeya et al., 2016). This extra cost has been a significant challenge to the adoption of hydroponic fodder into traditional livestock operations. Duncan et al., (2020) supported this assertion, concluding that adoption of these hydroponic technologies to improve feed production has been slow as there are few cases of fodder production leading to monetary gains, and producers are driven primarily by financial and market incentives.

Despite limited examples of financial success using fodder in a livestock operation, there are continued calls for further research into the topic due to various perceived benefits. These benefits include potential water conservation at the local level, the ability to produce feed with less land, and mitigating risks such as climate change and changes in fuel prices along with other challenges to conventional feed production (Girma and Gebremariam, 2019).

Data and Methods

A feed trial conducted by Utah State University's Animal Science department in the spring of 2023 looked to analyze the effects of using hydroponically produced barley fodder as a substitute for corn silage in a ration series to finish beef steers. Throughout the study, the Animal Science department operated the hydroponic fodder production system that produced the barley fodder. This system is fully automated within a rectangular 10 ft. by 20 ft. metal container and once it is set up, only requires the user to supply new barley seeds, remove the mature fodder daily, and occasionally clean the system. Water is autonomously added as needed by the system. Within the box, trays of the barley seeds are rotated through a 7-day growing system that allows the barley seeds to grow into sprouts and be fed to livestock as fodder. Data collected on this system included the amount of seed input into the system, the amount of water consumed, the amount of labor it took to operate the system, and the total fodder output from the system.

Before beginning the trial, 60 steers were sourced between Utah State's beef herd and a private herd in Nephi, Utah. At the start of the trial, the steers were split randomly into two groups. The control group (CON) was fed a conventional ration series that included alfalfa, corn silage, barley, and a mineral supplement. The barely fodder (BF) treatment group was then fed a ration series that included alfalfa, barley, mineral supplement, and fodder. During the study each group went through 4 steps of their respective ration series. Each step was balanced between the two groups to achieve similar nutrient value and steps 1 through 3 were meant to adjust the steers to their final finishing ration prior to slaughter. Ration "step 1" lasted 8 days, while "step 2" and "step 3" each lasted 7 days. The final finishing ration, "Step 4" was fed for the remaining 106 days of the total 128 days on feed (DOF). Table 1 summarizes the components of each step of the feed ration series.

Table 1. Feed Trial Ration Series

Step 1					
Control			**Fodder**		
	lbs AF	%AF		lbs AF	%AF
Fodder	0	0%	Fodder	35	65%
Alfalfa	6	17%	Alfalfa	8	15%
Corn Silage	18	52%	Corn Silage	0	0%
Barley	10.5	30%	Barley	10.9	20%
Mineral	0.25	1%	Mineral	0.25	0.5%
Total lbs	34.75		Total lbs	54.15	

Step 2					
Control			**Fodder**		
	lbs AF	%AF		lbs AF	%AF
Fodder	0	0%	Fodder	35	65%
Alfalfa	4.5	14%	Alfalfa	6.1	11%
Corn Silage	15	46%	Corn Silage	0	0%
Barley	13	40%	Barley	12.6	23%
Mineral	0.25	1%	Mineral	0.25	0.5%
Total lbs	32.75		Total lbs	53.95	

Step 3					
Control			**Fodder**		
	lbs AF	%AF		lbs AF	%AF
Fodder	0	0%	Fodder	35	65%
Alfalfa	3	10%	Alfalfa	3.5	6%
Corn Silage	11	36%	Corn Silage	0	0%
Barley	16	52%	Barley	15	28%
Mineral	0.5	2%	Mineral	0.5	1%
Total lbs	30.5		Total lbs	54	

Step 4					
Control			**Fodder**		
	lbs AF	%AF		lbs AF	%AF
Fodder	0	0%	Fodder	35	65%
Alfalfa	2	8%	Alfalfa	2	4%
Corn Silage	5	19%	Corn Silage	0	0%
Barley	19	72%	Barley	16	30%
Mineral	0.5	2%	Mineral	0.5	1%
Total lbs	26.5		Total lbs	53.5	

Within the CON group, alfalfa and corn silage were phased out of the ration mix in favor of more barley and additional mineral as the study progressed. Within the BF group, alfalfa was phased out of the ration mix in favor of more barley and additional mineral while the percentage of fodder was held constant at 65% on an “as fed” basis. It is important to note that the heavier fodder ration can be explained by the additional water weight included in the wet fodder. Each steer received an electronic identification collar (EID) used to monitor individual feed consumption and other feeding patterns daily using Growsafe feed bunks (Vytelle, 2024). At the conclusion of the 128-day feeding period, the steers were slaughtered at a commercial slaughter facility and their carcasses were analyzed and the data recorded for comparison. The data from this study was used to determine the range in performance of steers on the different rations, along with the costs to produce fodder for the current analysis. Summaries of the findings comparing the two groups are found in Table 2.

Table 2. Feed Trial Results Summary

Characteristic Averages	Control	Fodder
Beginning Weight	844 lbs.	850 lbs.
Final Live Weight	1325 lbs.	1307 lbs.
Carcass Weight	792.5 lbs.	794.9 lbs.
Quality Grade	2.5	2.3
Yield Grade	2.8	3.2
Total Gain	481 lbs.	457 lbs.
Daily Gain	3.76 lbs.	3.57 lbs.

This current study seeks to estimate the expected COG and net returns over feed costs for both the CON and BF treatment groups using the feeding trial data gathered as part of the feeding trial. To complete the objectives of this study, additional publicly available data was collected to complete the financial analysis. This included data on both the costs and returns for finishing cattle on the rations used in the feeding trial. Feed and cattle historical prices were gathered for the years 2018-2023. The range of 6 years was selected as it gives us a series of values before and after the COVID-19 pandemic in the United States. The pandemic is considered to have begun in late 2019 when cases were first reported in the United States, and is considered to have ended in May of 2023 when the United States Public Health Emergency designation expired. The effect of COVID-19 had a significant impact on agriculture and its prices as it forced supply chains into bottle necks and complete closure at times. Taking data from the last 6 years ultimately helps to mitigate the anomaly of the COVID-19 pandemic and its impacts while still staying relevant with current data. All price data was adjusted for inflation using the U.S. Bureau of Labor Statistics Consumer Price Index with a December 2023 base/reference year (U.S. BLS, 2024). The data used in this analysis was collected from the Mountain West region as a whole or individual states within the region depending on data availability and reliability, to remain within the scope of the analysis.

A stochastic model was constructed to compare the total feed input costs to the total revenue generating the net return over feed costs to the operation. Palisades's @Risk software program (Lumivero, 2024) was used to complete the simulation. Allowing for stochastic variation introduces "real world" risk and variability to the analytical model. The @Risk software program allows users to analyze variables within a dataset by fitting distributions to the observed values. Distributions can be selected for a variable that offer the 'best' fit with the 'best' determined by various goodness of fit metrics. Within this study the Akaike Information Criterion, or AIC was relied upon to make distribution selections. AIC is a measure of model quality that allows models to be compared directly to one another. The distributions fit to observed data can then be used in the calculation of output metrics such as cost of gain and expected net return to allow for risk and variability. Using @Risk to produce a stochastic model is advantageous over a non-stochastic model as it allows us to capture a range of realistic outcomes allowing the user to make a more informed real-world decision. A non-stochastic model would only represent one outcome for an output which offers limited information in most real-world decision-making scenarios.

Costs

Feeder cattle operations operate by buying calves and feeding them a high energy diet until they are large enough to slaughter. The main costs incurred to the operation come from the cost of purchasing the steer calves to be fed, and the cost of the feed. The first piece of data analyzed to understand finishing calves on fodder was the beginning weight for each group of steers which was collected during the feed trial. Using @Risk to fit a function to each group's beginning weight, the best fit for the beginning weight of the CON group was a normal distribution, and the best fit for the BF group was a uniform distribution. However, using these fitted functions allowed for unrealistic maximum and minimum weights which could skew results with unrealistic returns. To mitigate this issue, the functions were truncated to set boundaries on the function to + or - 20% of the observed maximum and minimum values from the feeding trial. These functions are summarized in the appendix as Table A1.

Feeder steer price data was then needed to determine the total cost to purchase steers in conjunction with their weights. This data was compiled as a 3-state average for a range of steer weights from auction prices collected between Montana, Wyoming, and Colorado by the Livestock Marketing Information Center (LMIC, 2024). The non-stochastic average price of $170.25/cwt for the feeder steers in the 800-900 lbs. weight range was used in the analysis. This variable was chosen to be non-stochastic as the majority of the steers had a beginning weight in this range and to prevent unnecessary and excessive variation in the model. The same beginning feeder steer price was used between both the CON and BF group as the fodder treatment had not been applied yet and there should be few differences between the steers.

Both the weight and price functions were then used to determine the initial cost of purchasing steers for each group using the following equation:

1) $$Cost\ to\ Purchase\ Steer = \frac{Beginning\ Weight\ (lbs) \times Feeder\ Steer\ Price\ (\$/cwt)}{100}$$

With the cost of the steers calculated, the next pieces of data collected were the prices for the feed rations used in the feed trial. Rations for the CON group were comprised of alfalfa, corn silage, feed barley, and mineral. Rations for the BF group were comprised of the same components, with the exception of corn silage being substituted out for the hydroponically produced barley fodder. Data used to determine the price of alfalfa came from the monthly price per ton dataset for Utah compiled by USDA, NASS. The analysis of the price of corn silage was conducted using the Colorado monthly grain corn price $/bu dataset provided by USDA, NASS. To convert these prices to corn silage prices, each nominal $/bu was multiplied by 9 as the price of corn silage ($/ton) is approximately 9 times greater than the corn price per bushel (Feuz, 2012). These nominal values were then converted to real prices to give us our real corn silage price per ton. Feed barley prices were analyzed using Idaho monthly feed barley $/bu prices provided by USDA, NASS. These prices were then converted into $/pound by dividing them by the average weight (48 lbs.) of a barley bushel as defined by the USDA NASS (2009). An additional cost of $0.003215 was added to the cost of each pound of feed barley for the processing of the feed barley. For barley to be effectively digested by cattle, it needs to be processed and rolled which costs approximately $6.43 for every ton of barley processed when adjusted for inflation (Boyles, Anderson, and Koch, 2015). For alfalfa and corn silage, distributions were selected outside of their "best fitting" functions as determined by AIC in order to reflect more economically realistic distributions. Alfalfa was best fit with a Kumaraswamy distribution which placed a greater likelihood on the price extremes rather than the mean cost per ton. A triangle distribution was instead used to focus the distribution around the mean as the most likely outcome. Corn silage was best fit by the uniform distribution which placed equal likelihood of an outcome across all potential prices. A triangle distribution was selected instead to place more emphasis around the mean price per ton as the most likely outcome. Mineral prices were entered into the analysis as a non-stochastic value taken as the average price of mineral for the feeding trial of $800 per ton. Each feed component cost function is summarized in Table A1.

The price of hydroponically produced barley fodder is thought to be highly dependent on the production system used. For this analysis the price per pound (as fed) of the barley fodder was estimated using data gathered from the USU barley fodder production box. To convert input costs to a cost per pound of produced fodder basis, the daily total pounds of produced fodder from the 128-day feeding trial was fit with a distribution to provide a range of potential daily production outcomes while it operated at maximum capacity. The best fitting distribution was found to be a triangle distribution. Calculating the costs of fodder production while assuming peak operational capacity implicitly assumes maximum efficiency and minimizes the costs of production. Individual producers may not be able to achieve these efficiency levels which would increase the assumed costs of fodder production. In part, for this reason, a sensitivity analysis around the simulated results was conducted.

Variable input costs within the hydroponic fodder system were also characterized. The first variable cost was the labor to operate the system. During the feeding trial it was estimated that it took anywhere from 20 to 30 minutes per day to operate the fodder production system.

This involved performing the necessary tasks to remove the fodder sprouts to be fed and add new seeds, water, and cleaning when needed. To capture this variation in the amount of time required to operate the system, a uniform distribution for labor was assigned to reflect the expected daily labor requirement between 20 to 30 minutes a day. The labor rate per hour relied on annual data from USDA, NASS for the average crop and animal worker wage for the Mountain West region. These nominal wages were converted to a real wage rate and fit to triangle distribution. To determine the total cost of labor per pound of produced fodder, the following equation was used:

2) $$Labor\ Cost\ per\ Pound\ of\ Produced\ Fodder = \frac{Labor\ Wage\ Rate\left(\frac{\$}{hr}\right) \times Daily\ Labor\ Time(hrs.)}{Daily\ lbs.\ of\ Produced\ Fodder\ Sprouts}$$

Another variable input in the production of fodder is water. Daily water usage within the feeding trial was recorded for use in this analysis. By dividing this water usage by the daily total fodder production, we calculated the gallons of water per pound of produced fodder. A distribution was fit to this data with an extreme value distribution selected according to best fit. To assign a cost to a gallon of water, data from the state of Utah was used (DNR, 2010). According to this data, 1000 gallons of water cost $2.42 on average in the Western U.S. in 2006. After adjusting for inflation and dividing by 1000, we assumed an average cost of $0.0037 per gallon of water. A triangle distribution was assigned with an upper limit of $0.0055 and a lower limit of $0.0018 to capture movements of 50% in the water rate. With the water consumption and cost functions, the cost of water per pound of fodder was then found with the following equation:

3) $$Water\ Cost\ per\ Pound\ of\ Produced\ Fodder = Gallons\ of\ Water\ per\ Pound\ of\ Produced\ Fodder \times Cost\ per\ Gallon\ of\ Water$$

The next variable cost analyzed was electricity per pound of produced fodder. The average electricity usage was assumed to be 0.196 KWh/lb. of produced fodder. This value was provided to us by Renaissance Ag. as the observed average for one of their commercial hydroponic fodder production units. To determine the cost of a KWh, data was collected for the average cost per KWh in the Mountain region (U.S. BLS, 2024). A distribution was fit to these inflation adjusted rates with an extreme value distribution selected. The cost of electricity per pound of produced fodder was described by the equation below:

4) $$Electricity\ Cost\ per\ Pound\ of\ Produced\ Fodder =$$

$$0.1961875\ KWh\ per\ Pound\ of\ Produced\ Fodder \times\ Cost\ per\ KWh$$

The final variable cost incurred to produce the hydroponically grown fodder is the cost of the barley seed per pound of produced fodder. Hydroponic fodder production requires a higher quality seed that will reliably sprout and grow in hydroponic systems. To reflect the higher cost of these seeds, malting barley price data provided by USDA, NASS was used to capture the higher priced seeds compared to regular feed barley. Operating at maximum capacity, the USU fodder production system requires 240 pounds of barley seed per day. The barley seed cost per pound of fodder production was then calculated as in:

5) $$Barley\ Seed\ Cost\ per\ Pound\ of\ Produced\ Fodder =$$

$$\frac{Cost\ of\ Malting\ Barley\ per\ Pound \times 240\ lbs.\ of\ Seed}{Daily\ lbs.\ of\ Produced\ Fodder\ Sprouts}$$

Table A1 summarizes the fitted expense functions used to determine the cost of fodder production.

Determining the fixed cost to produce fodder only involves purchasing the growing system. The Utah State University fodder production system has an initial cost of $30,000. A 10% salvage value and a 20-year useful life was assumed meaning a user could expect to incur an annual depreciation expense of $1,350 (straight line depreciation method). By multiplying our daily pounds of fodder sprout produced function by 365, we got an annual total fodder production value. Dividing the annual depreciation expense by the total annual fodder production, a depreciation expense per pound of fodder produced was calculated as in:

6) $$Depreciation\ per\ Pound\ of\ Produced\ Fodder = \frac{\frac{\$30{,}000(1-10\%)}{20}}{Daily\ lbs.\ of\ Produced\ Fodder\ Sprout \times 365}$$

With both the variable and fixed expenses calculated on a per pound of produced fodder basis, the following equation was used to determine the overall cost per pound of produced fodder:

7) $$Cost\ per\ Pound\ of\ Produced\ Fodder = Labor\ Cost\ per\ Pound\ of\ Produced\ Fodder + Water\ Cost\ per\ Pound\ of\ Produced\ Fodder + Electricity\ cost\ per\ pound\ of\ Produced\ Fodder + Barley\ Seed\ Cost\ per\ pound\ of\ Produced\ Fodder + Depreciation\ per\ pound\ of\ Produced\ Fodder$$

With all costs calculated for each component of the ration series, the cost for each individual ration was then calculated. By taking the percentage of each component as fed (Table1) in each ration step and multiplying it by their respective cost per pound functions defined in Table A1, the average estimated cost for each ration is shown in Table 3:

Table 3. Estimated Ration Costs As-Fed

	Step 1		Step 2	
	Control	**Fodder**	**Control**	**Fodder**
	Cost $	Cost $	Cost $	Cost $
Fodder	$0.00	$1.30	$0.00	$1.13
Alfalfa	$0.75	$0.84	$0.49	$0.55
Corn Silage	$0.48	$0.00	$0.35	$0.00
Barley	$1.14	$1.49	$1.22	$0.99
Mineral	$0.11	$0.09	$0.09	$0.08
Total Ration Cost ($)	**$2.48**	**$3.72**	**$2.14**	**$2.75**
Ration Total Average Consumption (lbs.)	**37.23**	**48.55**	**30.24**	**41.88**
Ration Cost ($/lb. as fed)	**$0.07**	**$0.08**	**$0.07**	**$0.07**
	Step 3		**Step 4**	
Fodder	$0.00	$1.34	$0.00	$1.50
Alfalfa	$0.38	$0.38	$0.28	$0.24
Corn Silage	$0.30	$0.00	$0.15	$0.00
Barley	$1.77	$1.41	$2.29	$1.67
Mineral	$0.22	$0.18	$0.24	$0.21
Total Ration Cost ($)	**$2.66**	**$3.31**	**$2.95**	**$3.62**
Ration Total Average Consumption (lbs.)	**33.13**	**49.88**	**31.41**	**55.09**
Ration Cost ($/lb. as fed)	**$0.08**	**$0.07**	**$0.09**	**$0.07**

As shown in table 3, total costs increased as more barley was incorporated. The total cost of each ration step was more expensive for the BF group compared to the CON group. On a per pound as-fed basis, the BF group was more expensive in steps 1 and 2, while the CON group was more expensive in steps 3 and 4. This was due to the more expensive raw barley being fed to the CON group while the BF group was fed the hydroponically produced barley fodder which included a significant amount of water weight decreasing the cost per pound on an as-fed basis for each ration step.

While the costs for each ration step were compiled, an additional step needed to be taken to account for the variability in consumption by the steers. Distributions were fit to the individual animal consumption data from each step of the ration and within each treatment. Table A1 highlights the fitted functions for each ration step within each treatment. The functions for the control groups step 2 and 4 along with fodder groups steps 2, 3, and 4 were truncated to limit unrealistic scenarios in the simulation assumed when selecting a distribution with an infinite maximum or minimum. With these consumption functions for each step, they were then used in conjunction with the price data to determine the expected total cost of the ration step per head/day. Since consumption is only measured in total pounds of the ration eaten and not the individual components, the cost for each component in the ration was calculated as a percentage of the total ration as in:

8) $$Cost\ of\ Feed\ Component\ Consumed = Ration\ Step\ Consumption \times Percentage\ of\ Feed\ Component\ in\ the\ Ration\ Step \times Feed\ Component\ Price$$

The summation of each component's cost determines the total cost for the ration step per head/day:

9) $$Daily\ Cost\ per\ Ration\ Step = Cost\ of\ Fodder\ Consumed + Cost\ of\ Alfalfa\ Consumed + Cost\ of\ Corn\ Silage\ Consumed + Cost\ of\ Barley\ Consumed + Cost\ of\ Mineral\ Consumed$$

These individual ration step costs were then compiled along with the days the steer was on the ration in the following equation to determine the total ration series cost for the ration series for each group:

10) $$Total\ Ration\ Series\ Cost = Daily\ Cost\ per\ Ration\ Step\ 1 \times 8\ Days + Daily\ Cost\ per\ Ration\ Step\ 2 \times 7\ Days + Daily\ Cost\ per\ Ration\ Step\ 3 \times 7\ Days + Daily\ Cost\ per\ Ration\ Step\ 4 \times 106\ Days$$

The total ration series cost for each treatment was added to the cost of purchasing a steer to determine the total expected cost of finishing a steer by treatment. The total cost per head could then be calculated with the following equation:

11) $$Total\ Cost\ per\ head = Total\ Ration\ Series\ Cost + Cost\ to\ Purchase\ Steer$$

Table 4 highlights the costs for each group at the average.

Revenue

Revenue in a feeder cattle operation is generated by the sale of the finished steers to a slaughter facility where they are processed into their final products. This revenue for the feeder cattle operation is specifically determined by the carcass weight of the slaughtered steer and its quality characteristics. This variation in quality adds variation to price as it can create a positive or negative basis from the base dressed steer price. Quality characteristics examined in this analysis included yield grade and quality grade. The yield grade reflects the percentage of the carcass weight that can be trimmed and sold in the retail market. Yield grade is scored on a scale from 1 to 5, with 1 being the most desirable as it is the highest yielding carcass and 5 being the lowest yielding carcass. Quality grade is a qualitative categorical rating defined by the USDA to measure quality correlated with marbling level (Meadows, 2013). Qualities range from Prime, Choice, Select, and Standard in descending order of expected quality. An operation will see greater revenue on steers that score high on both yield and quality grade. The weight of the carcasses also can create basis from the based dressed steer price per cwt as the two are inversely correlated.

To begin to analyze the revenue from the feeding trial, a distribution was fit to each group's carcass weight data. The control carcass weight was best fit by a uniform distribution while the fodder carcass weight was best fit by an extreme value distribution (both described in Table A1). The fodder carcass weight function included a truncation limiting extreme high and low values from the analysis.

With the carcass weight functions completed, the base dressed steer price was next determined using dressed steer price data from Montana, Wyoming, and Colorado (LMIC, 2024). The best fitting distribution was found to be a triangle distribution which created the base dressed steer price per cwt. Triangle distributions were also defined for yield, quality, and carcass weight ranges to help determine the expected dressed price using grid pricing. The triangle distributions for these grid pricing variables were taken from the reported range and simple average from the AMS Monthly Slaughter Premiums and Discounts as reported for March 18, 2024. A summary of these functions is found in Table 3. The yield and quality grades for each simulated observation were drawn from the empirically observed distributions for each treatment. To account for presumed positive correlation between beginning weight and ending weight the correlation between the beginning weight of the steers and the carcass weight for each treatment group were set at 0.5.

The previously discussed carcass weight functions were used to determine the weight of the carcasses for each steer. The final expected carcass price ($/CWT) for each treatment was then calculated as in:

12) $$Individual\ Carcass\ Price\ per\ CWT = Base\ Dressed\ Steer\ Price\ + Yield\ Grade\ Basis + Quality\ Grade\ Basis + Carcass\ Weight\ Basis$$

The expected revenue per head was then calculated for each treatment group as in:

13) $$Total\ Revenue\ per\ Head = \frac{Individual\ Carcass\ Price\ (\$/cwt) \times Carcass\ Weight}{100}$$

With our total revenue per head calculated and our total cost per head calculated, we then determined our expected net return over feed costs per head for both treatment groups as the difference between revenue and costs as in:

14) $$Net\ Return\ Over\ Feed\ Costs = Total\ Revenue\ per\ Head - Total\ Cost\ per\ Head$$

Using the above analysis and the final live weight data, we next determined the cost of gain ratio for each group within our stochastic model. Distributions were fit to the final live weights for both treatments with the best fitting distributions selected and summarized in Table A1. The total gain by treatment was then estimated as the difference in Final Live Weight and Beginning Weight. The expected cost of gain ratio was then estimated as in:

15) $$Cost\ of\ Gain = \frac{Total\ Ration\ Series\ Cost}{(Final\ Live\ Weight - Beginning\ Weight\ )}$$

The simulation of $Cost\ of\ Gain$ and *Net Return Over Feed Costs* are the primary focus to accomplish the objectives.

Results

With the analysis completed as described above, the average costs and revenue are highlighted in Table 4.

Table 4. Cost and Returns by Treatment Calculated at Means

Steer Costs		
	Control	**Fodder**
Beginning Weight (lbs.)	844	850
Beginning Price ($/cwt.)	$170.25	$170.25
Feeder Steer Cost ($/hd.)	**$1,436.91**	**$1,447.13**
Feed Costs		
	Control	**Fodder**
Daily Feed Consumption (lbs.)	37.23	48.55
Cost of Ration ($/lb.)	0.066711544	0.076674693
Cost of Ration ($/day)	2.48367077	3.722556322
Total Feed Cost Step 1 (8 days)	$19.87	$29.78
Daily Feed Consumption (lbs.)	30.24	41.88
Cost of Ration ($/lb.)	0.070911982	0.065740424
Cost of Ration ($/day)	2.144378342	2.753208944
Total Feed Cost Step 2 (7 days)	$15.01	$19.27
Daily Feed Consumption (lbs.)	33.13	49.88
Cost of Ration ($/lb.)	0.080368956	0.066421238
Cost of Ration ($/day)	2.662623515	3.313091362
Total Feed Cost Step 3 (7 days)	$18.64	$23.19
Daily Feed Consumption (lbs.)	31.41	55.09
Cost of Ration ($/lb.)	0.093945925	0.065658192
Cost of Ration ($/day)	2.950841489	3.617109812
Total Feed Cost Step 4 (106 days)	$312.79	$383.41
Total Ration Series Cost (128 days)	**$366.31**	**$455.66**
Steer Revenue		
	Control	**Fodder**
Carcass Weight (lbs.)	791.5	795.58
Dressed Price ($/cwt.)	$228.50	$229.02
Total Revenue ($/hd.)	$1,808.58	$1,822.04
Net Return ($/hd.)	**$5.36**	**-$80.75**

Cost of Gain Analysis

The cost of gain is a key efficiency metric used by many cattle finishing operations to determine how efficiently they can put weight on cattle. The lower the cost of gain, the more efficient an operation is. The simulated probability distribution function (PDF) and cumulative descending function (CDF) from our model for the expected cost of gain as in equation (15) is contained within Figure 1 and Figure 2. These graphs highlight the range and probabilities of the various potential cost of gains for each treatment group.

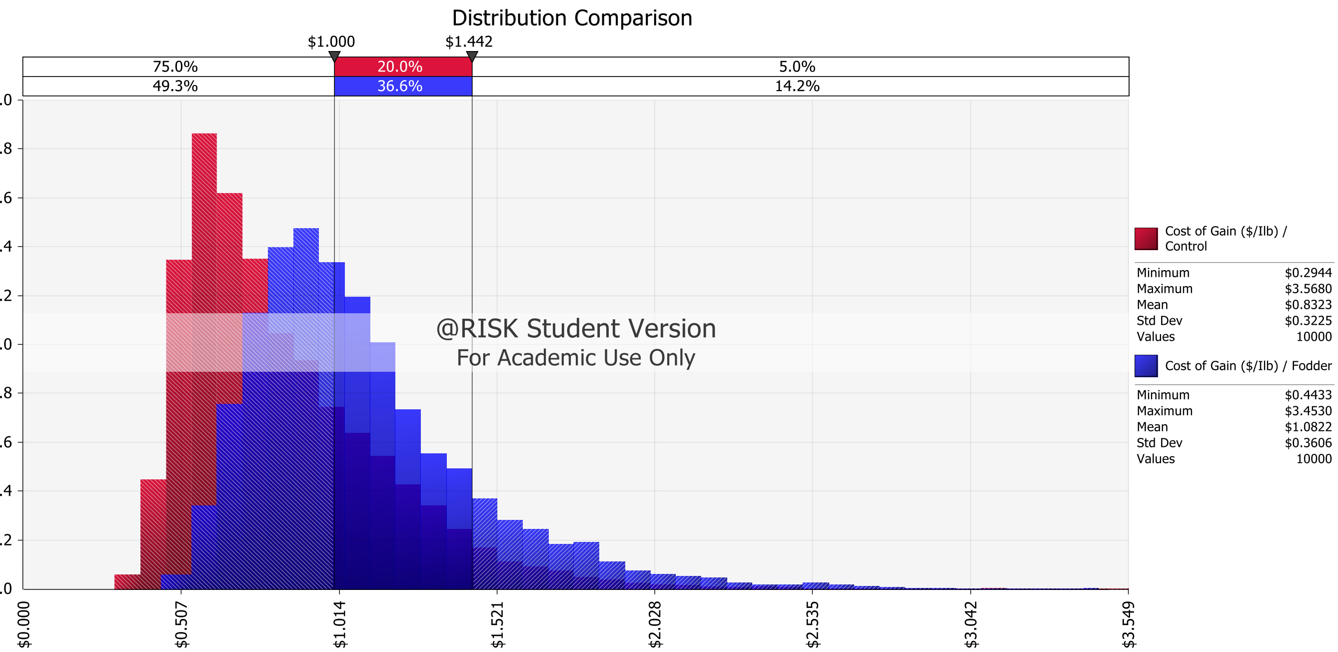

Figure 1. Cost of Gain PDF and Summary Statistics

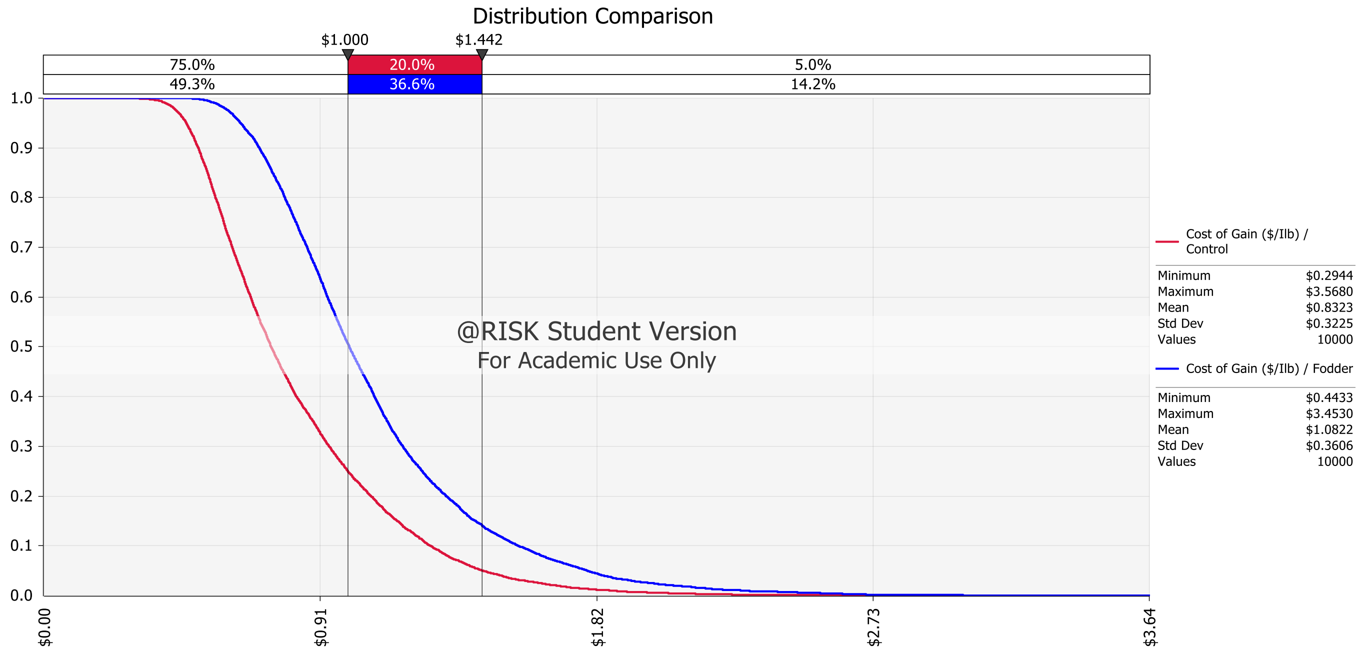

Figure 2. Cost of Gain CDF and Summary Statistics

As shown by the PDF and CDF, the COG for the BF treatment group has greater variability and with a lower maximum, while the COG for the CON group has less variation and a smaller minimum. It also shows that we can expect that 75% of the time, the COG for the CON group will be less than $1.00/lb., while it has a 25% chance of being above $1.00. The BF COG is expected to have a nearly equal probability of being less than and greater than $1.00/lb. (49.3% and 50.8% respectively). The average COG for the BF group is $1.08/lb. while it is only $0.83/lb. for CON. This cost of gain analysis suggests that it is more economically efficient to finish steers on a conventional ration than on a hydroponically produced barley fodder ration. However, this PDF shows that there are scenarios in which the cost of a conventional ration increases so much that the fodder-based ration is cheaper which will be further discussed in the sensitivity analysis.

Expected Net Return Analysis

The simulated PDF and CDF for expected net return over feed costs as in equation (14) is contained within Figure 3 and Figure 4. These graphs highlight the range of potential returns per head.

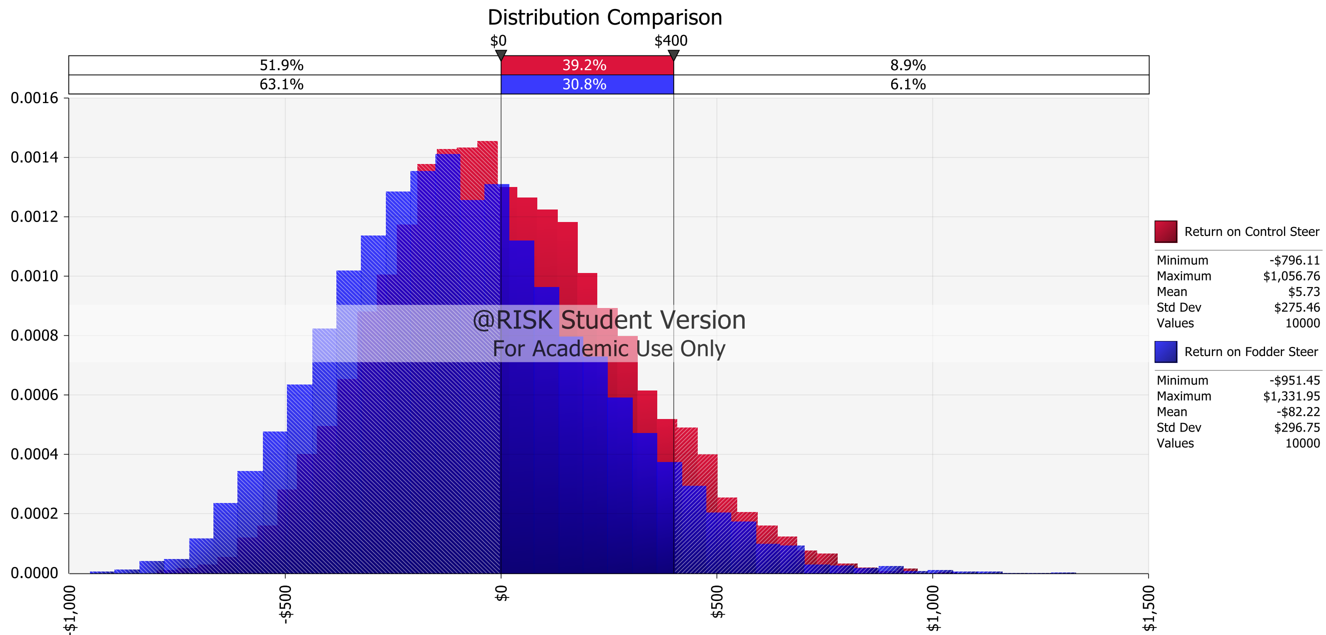

Figure 3. Expected Net Returns PDF and Summary Statistics

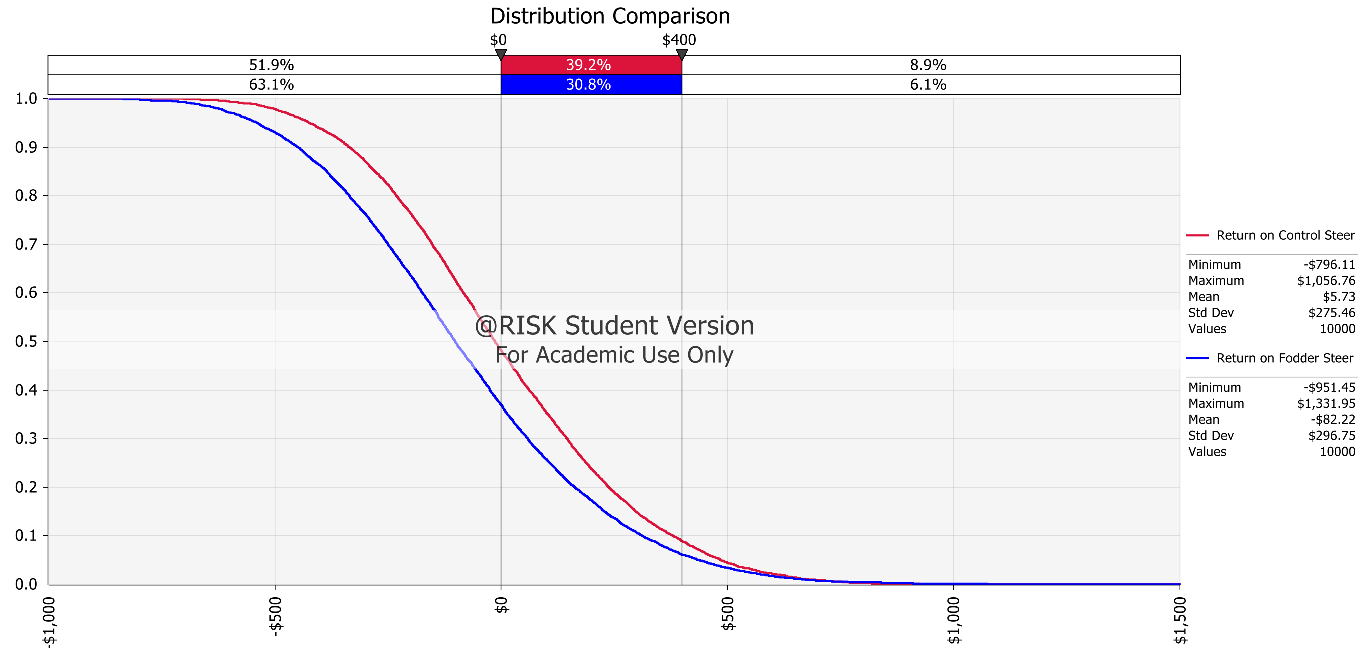

Figure 4. Expected Net Returns CDF and Summary Statistics

Based upon the PDF and CDF, we see that both treatment groups have similar overall distributions but different returns per head. When looking at the CON group specifically, we can expect a 48.1% probability for an operation seeing a positive return for the CON treatment. It also shows us that there is a 51.9% probability of a negative return for this treatment. For the BF treatment group, the probability of a positive net return is reduced to 36.9% and while the probability of a negative return is increased to 63.1%. This demonstrates that the chance for a positive return is greater for the CON treatment as compared to the BF treatment. Summary statistics from the table show that the average return for the CON group is expected to be $5.73/hd., while the average return for the BF group is -$82.22/hd. The minimum return for the CON group is -$796.11/hd., and the minimum expected return for the BF group is -$951.45/hd. Maximum potential returns for the CON group are $1,056.76/hd., while the maximum potential returns for the BF group are $1,331.95/hd. Standard Deviation is $275.46/hd. for the CON group while it is $296.75/hd. for the BF group showing the marginally tighter distribution of the CON group as seen in the PDF.

Sensitivity Analysis

A sensitivity analysis was conducted with this model to better understand the consistency of our results, and determine which variables are the most influential on the cost of gain between treatments. Variables analyzed included the cost and expected useful life of the USU barley fodder production box, inputs of the box, and the costs of the conventional feed inputs. Shifts applied to the initial cost of the box resulted in minimal changes to the results. If the cost of the box were reduced to $0, then the cost of producing fodder is less expensive. However, it only reduces cost of gain for the BF group by $0.03/lb. relative to our base analysis. This marginal reduction is not sufficient to bring the BF cost of gain to a comparable level with the CON cost of gain. This shows that the cost of the box has little influence on our analysis. Shifts applied to the useful life of the box also result in minimal changes from the base analysis. It is determined that by increasing the useful life of the box from 20 years to 50 years, the depreciation expense included in the fodder costs would decrease. However, the BF cost of gain would only decrease by $0.02/lb. which does not bring the group's cost of gain down to comparable levels with the CON group's cost of gain. Significant shifts to the mean in the cost of alfalfa function are required to have any meaningful impact on the overall results and the BF group cost of gain remained more expensive. Increasing the cost of alfalfa per ton by 1,000% (or to a mean of $2,340 per ton) results in a simulated $1.68/lb. cost of gain for the CON group and a $1.88 cost of gain for the BF group. Decreasing the mean cost of alfalfa also does not have a meaningful impact on the results. Shifts applied to the price of corn silage were more impactful to the results of the analysis as they only impacted the CON group's ration. By increasing the price of corn silage per ton function by 500% (or to a mean of $250 per ton) the CON cost of gain and BF cost of gain break even at $1.05/lb. This shows that if the price of corn silage were to be more than $250 per ton, the BF ration would lead to a lower cost of gain compared to the CON ration. The price of corn silage increasing by 500% is highly unlikely though as our data only shows an increase from our mean of 50% at our maximum price over the last 6 years. This scenario is still important to consider as corn silage is a key part of the CON ration. Shifts were applied to both feeder barley and malting barley. When both barley type functions were increased or decreased together, minimal changes to the overall analysis occur. However, if only one type was shifted at a time, then changes to the overall analysis are seen. If the mean price of the feed barley function is increased by 256%, then the cost of gain for both groups breakeven at $1.75/lb. If the mean price of the malting barley function is decreased by 88%, then the cost of gain for both groups breaks even at $0.83/lb. However, feed barley and malting barley prices are expected to be highly correlated which would suggest that these break-even scenarios would be unlikely in reality. When the mean electricity, labor, and water cost functions are each individually dropped to $0, the change in the BF group cost of gain only decreases between $0.02 to $0.05/lb. The results of this sensitivity analysis suggest that our base analysis and its implications that using hydroponically grown barley fodder is not financially feasible when compared to using conventional feed to finish steers are not sensitive to realistic changes in input costs. Only with excessive shifts to the mean of the cost functions are significant changes to the base analysis seen.

Limitations

This financial analysis was completed using the predetermined control and fodder ration series from the USU feeding trial. There may be other rations that include hydroponically produced barley fodder that reflect different returns per head as they are composed of different feed components and make up different percentages of the ration. Each new fodder-based ration would likely have a new range of potential cost of gain ratios and returns per head which could prove more or less favorable than within this current analysis.

Conclusion

Based upon our stochastic model and analysis results, the fodder finished steers are expected to have a higher cost of gain when compared to the control steers finished with a conventional ration. Fodder finished steers have an average cost of gain that was $0.25/lb. higher than the average cost of gain for conventionally finished steers. The minimum cost of gain that can be achieved in our model is also lower for the conventionally fed steers compared to the fodder fed steers by $0.15/lb. However, the maximum cost for gain for each group shows that the conventionally fed steers could be more expensive to finish with a cost of gain $0.11 greater than the barley fed steers suggesting that there are scenarios where it is cheaper to finish steers on hydroponically produced barley fodder. A sensitivity analysis demonstrates that these cases are practically unrealistic as they would require non-fodder feed prices to increase to extremes such as the mean price of corn increasing by 500% or more. Another example of one of these scenarios would be if the price of malting barley dropped significantly while feed barley remains constant which is unlikely as these prices are strongly correlated. Our analysis of the net return per head also shows similar results with a greater mean return and minimum return for the conventional group, and a greater maximum return for the fodder fed group. However, the distribution of potential returns for the conventionally fed steers is more favorable as it shows a 48.1% chance of a positive return while the fodder fed steers have a 36.9% chance of a positive return. These results suggest that using hydroponically produced barley fodder to finish steers is expected to result in increased COG and lower expected net returns over feed costs per head as compared to finishing steers using a conventional mixed ration.

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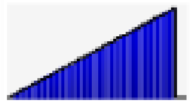
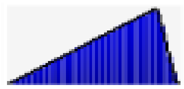
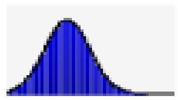
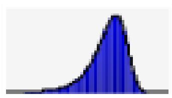
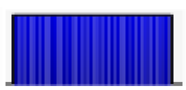
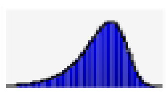
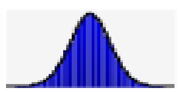
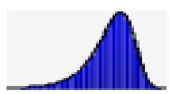
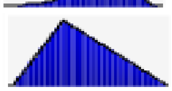
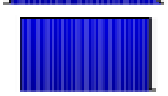
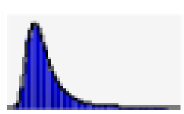
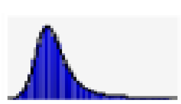
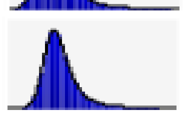
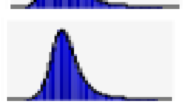
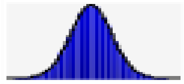
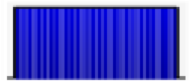
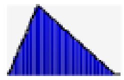
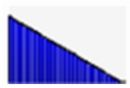
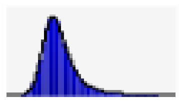
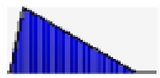
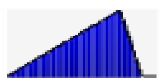
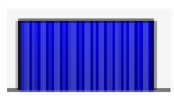
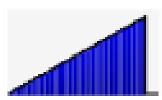
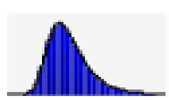
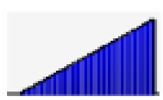
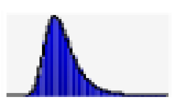
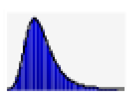
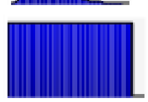
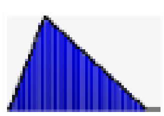
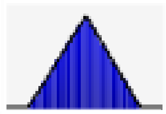
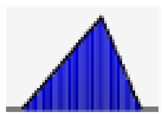
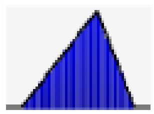
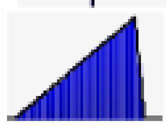
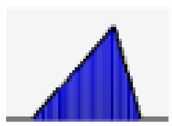
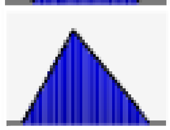
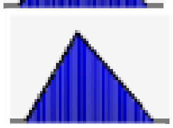
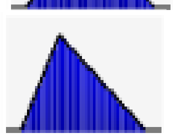
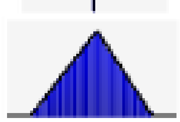
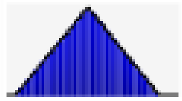
Appendix

Table A1. @RISK Functions for the Analysis

Variable	Fitted Function	Distribution	Minimum	Maximum	Mean
Fodder Step 1 Avg Daily llbs of Consumption		Triangle	21.00	62.52	48.55
Control Step 1 Avg Daily llbs of Consumption		Triangle	26.42	43.62	37.23
Fodder Step 2 Avg Daily llbs of Consumption		Normal	21.11	70.65	41.88
Control Step 2 Avg Daily lbs of Consumption		Extreme Value Minimum	9.43	39.86	30.24
Fodder Step 3 Avg Daily llbs of Consumption		Uniform	36.40	63.36	49.88
Control Step 3 Avg Daily lbs of Consumption		Extreme Value Minimum	17.21	43.59	33.13
Fodder Step 4 Avg Daily llbs of Consumption		Normal	37.43	72.88	55.09
Control Step 4 Avg Daily lbs of Consumption		Extreme Value Minimum	17.26	39.19	31.41
Fodder Final Live Weight		Triangle	1117.33	1544.32	1306.28
Control Final Live Weight		Uniform	1151.20	1486.82	1319.00
7-800 llb Feeder Steer Real $/cwt		Log-Logisitc	148.74	308.41	179.05
8-900 llb Feeder Steer Real $/cwt		Log-Logisitc	125.73	292.98	170.25
9-1000 llb Feeder Steer Real $/cwt		Log-Logisitc	117.04	280.58	162.15
10-1100 llb Feeder Steer Real $/cwt		Log-Logisitc	103.98	261.56	152.78

Control Beginning Weight		Normal	618.74	1,063.43	843.73
Fodder Beginning Weight		Uniform	714.25	985.74	850.00
Alfalfa Real $/ton		Triangle	163.13	329.88	234.01
Feed Barley Real $/pound		Triangle	0.06	0.15	0.10
Malting Barley Real $/pound		Log-Logistic	0.11	0.17	0.13
Estimated Silage Real $/Ton		Triangle	31.51	81.31	49.94
lbs. of Sprouts Grown per Day		Triangle	955.36	1357.03	1200.8
Hour/Day to Operate Renaissance Ag System		Uniform	0.33	0.50	0.42
Real Wage/Hour		Triangle	12.11	17.52	15.70
Gallons of Water/Pound of Fodder Produced		Extreme Value	0.11	0.23	0.15
Real Water Cost/Gallon		Triangle	0.00	0.00	0.00
Real Cost/Kilowatt Hour		Extreme Value	0.13	0.19	0.14
Fodder Carcass Weight		Extreme Value	653.57	1121.85	795.58
Control Carcass Weight		Uniform	701.18	881.83	791.50
Real Dressed Steer Price $/CWT		Triangle	182.49	306.25	234.49

Quality Grade - Prime Basis		Triangle	0.02	24.94	12.63
Quality Grade - Choice Basis		Triangle	0.00	0.00	0.00
Quality Grade - Select Basis		Triangle	-21.92	-8.03	-14.23
Carcass Weight - 550-600 Basis		Triangle	-34.79	-0.20	-15.52
Carcass Weight - 600-900 Basis		Triangle	0.00	0.00	0.00
Carcass Weight - 900-1000 Basis		Triangle	-14.88	-0.01	-5.36
Carcass Weight - 1000-1050 Basis		Triangle	-19.85	-0.06	-8.33
Yield Grade - 1-2 Basis		Triangle	0.05	7.98	3.73
Yield Grade 2-2.5 Basis		Triangle	0.02	3.97	1.87
Yield Grade 2.5-3 Basis		Triangle	0.02	4.00	1.74
Yield Grade 3-3.5 Basis		Triangle	0.00	0.00	0.00
Yield Grade 3.5-4 Basis		Triangle	0.00	0.00	0.00
Yield Grade 4-5 Basis		Triangle	-14.99	-10.03	-12.42

Yeild Grade 5< Basis		Triangle	-24.97	-10.08	-17.48