An Optimization Technique for Ranch Management

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Water is a scarce resource; it is a vital resource in the production of crops for livestock that will directly impact supply chain costs. Many costs occur in poorly deployed irrigation systems that don't fully utilize land potential, thereby, not produce the proper yield of crops for livestock. An irrigation system can not only reduce initial set up and maintenance costs but reduces land waste while increasing yield of dry matter feed. This research presents a cost benefit analysis approach to determine the practicability of installing an irrigation system onto 54 acres of ranch land by employing the use of linear programming. Specifically, by examining factors that impact costs and production, a generalized model was developed to better understand how this system works on any ranch. These results indicate by optimizing land to its fullest capacity for dry matter, one can then maximize profits generated. This research found the profitability of employing an irrigation system is beneficial even at lower production yields when compared to land with no irrigation system.

Keywords: ranch management, optimization, economic analysis

INTRODUCTION

There are many different types of water sources in the United States. The first is groundwater which is defined as the water that has penetrated to the empty volume that exists between the sedimentary rock formation and preexisting cracks. This ground water will then reappear into different mediums such as streams, rivers, and lakes (Sophocleous, 2002). All this water is provided by rain and is used to refill many types of bodies of water. Surface water is any body of water that will reside on the surface of the Earth and will include both freshwater such as river and lakes and saltwater bodies of water like oceans. The other type of water that is produced will be through precipitation. Precipitation occurs when any liquid and frozen water that forms in the atmosphere falls to the Earth and collects either on the surface of the Earth or in the ground. It is one of the three steps of the global water cycle (Sophocleous, 2002).

The U.S. Geological Survey report states that the major use of ground and surface water is strictly dedicated to the use of irrigation. In fact, 42% of all fresh water was used for irrigation in 2015 (Dieter et. al., 2018). Water used for irrigation purposes will permit for proper crop production in regions of the United States where little precipitation is available and provides a boost to the moisture already present in the United States where humidity levels are sufficient. This has benefited the productivity and profitability of crops grown in the United States. In addition, 54% of reporting farms show that their profits are coming from integrated irrigation systems. However, 20% of harvested cropland currently employs some type of irrigation system (Dieter et. al., 2018).

Irrigation in the United States occurs in over 58 million acres of cropland and much of it is concentrated in the western United Sates (Sadler et. al., 2005). However, irrigation also occurs in the southwestern part of the United States. Out of all the states, Nebraska accounts for the majority of irrigated land in the U.S. with over 8.6 million acres of irrigated cropland (USDA, 2017). Texas is one of the top five states of most irrigated cropland. Based on the National Oceanic and Atmospheric Administration, Texas ranks 34 in overall precipitation compared to other states (Sadler et. al., 2005).

On average, Texas will receive an average 734 mm of water in a year (NOAA,2021). However, even with an exceeding average amount of rainfall in 2021 in the State of Texas, the United States Department of Agriculture has declared Webb County a drought-stricken area that on average will receive 22 inches of rain (NOAA,2021). This has made an impact on agricultural products as well as on livestock sustainability in this region. Currently 39.8% of the water supply supporting Webb County is coming from ground water, based on studies conducted by the Texas Water Development Board. There are already factors that are in play to help mitigate some of the demands on water that will help to reduce the strain that the Webb County population will have on our water supply. One major reduction will come in the form of irrigation conservation (NOAA, 2021).

IRRIGATION CONSERVATION

Irrigation conservation is defined as having the ability to do as much as one can with minimum water and land usage using management strategies. These strategies include reducing everyday water consumption or increasing the efficiency of land in which the water is going to be used. This will produce optimal results with the same amount of water or less (Sadler, et. al., 2005). This will lead to a byproduct of water saving with a direct utilization of low energy precision application systems. It is projected that by 2060 groundwater supplies will decrease by 32%. Therefore, in addition to supplies not being able to meet demands (TWDP, 2017), irrigation systems must be made to do the same with less.

Based on the data provided in table 1, Texas is one of the top four states in the entire country that uses the most percentage of irrigated agricultural acreage in the United States. In fact, irrigation in Texas accounts for 7.5% of the total acres that are currently being irrigated in the United States (USDA, 2017). Furthermore, with the total estimated water usage in Texas, 16.2 million acres feet, 57% of that is devoted to agricultural irrigation (TWDP, 2017). In addition, according to a report made by the Texas A&M AgriLife Extension, 4.7 billion state dollars rely on Texas produced agriculture (Schattenberg, 2021).

TABLE 1
USDA CENSUS OF AGRICULTURE REPORT DATA OF U.S. IRRIGATED AGRICULTURAL LAND

States	Share Percentage of U.S. Irrigated Agricultural Land
Nebraska	14.8
California	13.5
Arkansas	8.4
Texas	7.5
Idaho	5.9
Colorado	4.8
Kansas	4.3
Montana	3.6
Mississippi	3.1
Washington	2.9

Oregon	2.9
Wyoming	2.7
Missouri	2.6
Florida	2.6
Georgia	2.2
Louisiana	2.1
Utah	1.9
Arizona	1.6
Nevada	1.4
Michigan	1.2
All other states	10.1

This economic incentive for produce to be grown in the state will further motivate crop sustainability and help the state move away from reliance on imported goods. This report also shows that since the 1970s, farmers in Texas have been adopting different methods to reduce water consumption and wasteful land usage. For example, farmers have begun to use center pivot irrigation sprinklers which now account for 80% of sprinklers used on irrigated lands (Mader, 2010). In addition, farmers have also begun to rely heavily on weather predictions to determine when it is the optimal time to water the crops. However, this report does warn of not improving current methodologies to help reduce the potential strain an increase in human population will produce on our food supply chain.

OPTIMIZATION MODEL DEVELOPMENT

All operational research or optimization relies on the belief that the system that they are describing is going to be idealistic and may not include real world components such as policy changes or weather changes (Vico, 2017). These components will increase the risk of not being able to give a clear picture of how an optimization will truly behave once entirely implemented and therefore may not give a desired maximum profitability. Identifying risks and including them in an optimization model provides a clearer picture to any future outcomes.

Optimization uses various tools that aid in producing an efficient system that minimizes wastes and at the same time maximizes profitability. One common tool that is used is called linear programming. This has been proven to be extremely helpful in the field of agriculture and to aid in the production of livestock and crops (Lawrence, et. al., 2008). This has helped farmers primarily in the planning stages of developing a good hypothetical model to use. This is done when one collects data and develops an objective function that will help guide the user in determining the best possible outcome with the resources that are available (Lawrence, et. al., 2008). After this is achieved this will allow for the farmers to set future goals and to determine the time that one will need to see these goals accomplished. However, the task of the agricultural manager is to identify all possible miss happenings that may occur during the deployment of the model into a real-world scenario. This will provide foresight into any possible risks that may occur and will allow for the manager to develop contingencies in case these risks were to occur.

The objective of this research is to find a generalized formulation of an optimization model. The purpose is for this model to be able to work on any area of land. Therefore, an objective function that includes decision variables that aid in minimizing land usage to keep costs down while maximizing profit and possible yield of dry matter grass must be developed. The first step is defining symbols that will be used in the development of the linear programming model. For this to be a complete picture, definitions are also accompanied with the symbols. Hence, the following symbols are used in the LP model development:

a Number of acres.
rc Ratio of cow occupation in each area (acre).
r Ratio for the fixed portion in the total cost.
$1 - r$ Ratio for the variable portion in the total cost.

p Average sales price for each cow on an open market.
σ Average sales price per pound of dry matter feed.
y Average production of grasses per acre.
f Average amount of feed per cow.
s Average selling cost of dry matter feed.
n Number of years for payment.
rt Interest rate per period.

After defining the symbols, decision variables are needed to determine which quantities will change for the overall system to work to give a high profitability. Decision variables are defined by a quantitative amount that your model will ultimately find to give an optimal solution to the objective function problem. The decision variables are as follows:

C_i Number of cows that reside on a given land area i, where $i = 0, 1, \ldots, e$.
Y_j amount of dry matter feed that is produced on a given area j, where j = 0, 1, …, a - e.
U_j amount of dry matter feed that is eaten by chosen livestock on a given area j.
LG_j total land available for grass.
LC_i number of cows occupied per acre i.
L_l Land of acre l, where $l = 0, 1, \ldots, a$.

An objective function is developed to understand the relationships between the decision variables and the constraints of the system. The objective function is defined in terms of decision variables that can maximize the profit or minimize the costs. In this research, an LP is used to determine the maximum profitability for the system. This includes the overall price and cost of all expenditures. Therefore, this research project considers the profit obtained from selling cattle in an open market and the profit obtained from selling the surplus matter feed. The overall cost includes the fixed and variable costs of the ranch economic system. Lastly, the loan amount for the cattle ranch is also included. The objective function is defined as follows:

Maximize (Sales Price Per Cow × Cow) + (Sales Price per lb. of dry matter feed × (Yield – Use)) – (Total Cost) – loan payment per year. (1)

Using the defined symbols, the objective function is written in the following LP format:

$$Max\ Z = \sum_{l}^{e}(p \times C_l) + \sum_{j}^{a-e} s\left(Y_j - U_j\right) - \frac{\left(\frac{rt}{n}\right)\times PV}{1-\left(1+\left(\frac{rt}{n}\right)\right)^{-n}} - TC \quad (2)$$

Since there is limited resources in the form of land as well as available livestock, corresponding constraints are developed for this model. These constraints include available land for cattle and dry matter feed, the amount of yield produced on each acre of land is a constraint.

The first constraint is that the total land available is less than or equal to the land dedicated for both cattle and grass.

$$\sum_{l=0}^{a} L_l \leq \sum_{i=0}^{e} LC_i + \sum_{j=0}^{a-e} LG_j \quad (3)$$

where $a \geq$ e. If $i = 0$, then there is no land used for cows, while $j = 0$, then there is no land used for growing the matter feed.

The second constraint is that the land for cattle will have to be equal to the ratio of the cattle that occupy each acre.

$$\sum_{i=0}^{e} LC_i \leq \sum_{i=0}^{e}(rc \times C_i) \tag{4}$$

In general, $rc \geq 0.5$.

The third constraint is that the yield will have to be less than or equal to the average production of land per acre.

$$\sum_{j=0}^{a-e} Y_j \leq \sum_{j=0}^{a-e}(y \times LG_j) \tag{5}$$

The fourth constraint is that the use of land is less than or equal to the amount of feed per cow multiplied by the number of cows.

$$\sum_{j=0}^{a-e} U_j \leq \sum_{i=0}^{e} f \times C_i \tag{6}$$

The fifth constraint is that the selling of dry matter feed must be less than the difference between the yield and the use.

$$\sum_{j=0}^{a-e}[s \times (Y_j - U_j)] \leq \sum_{j=0}^{a-e} y \times LG_j - \sum_{i=0}^{e} f \times C_i \tag{7}$$

The last constraint states that the total cost will equal to the sum of the fixed cost plus the variable cost.

$$TC = VC + FC, \tag{8}$$

$$TC = \sum_{i=1}^{e}[(1-r) \times TC \times C_i] + (r \times TC) \tag{9}$$

Following shows the generalized LP formulation.

Subject to

$$Max\ Z = \sum_{l}^{e}(p \times C_l) + \sum_{j}^{a-e} s\left(Y_j - U_j\right) - \frac{\left(\frac{rt}{n}\right) \times PV}{1-\left(1+\left(\frac{rt}{n}\right)\right)^{-n}} - TC \tag{10}$$

$$\sum_{l=0}^{a} L_l \leq \sum_{l=0}^{e} LC_i + \sum_{j=0}^{a-e} LG_j \tag{11}$$

$$\sum_{i=0}^{e} LC_i \leq \sum_{i=0}^{e}(rc \times C_i) \tag{13}$$

$$\sum_{j=0}^{a-e} Y_j \leq \sum_{j=0}^{a-e}(y \times LG_j) \tag{14}$$

$$\sum_{j=0}^{a-e} U_j \leq \sum_{i=0}^{e} f \times C_i \tag{15}$$

$$\sum_{j=0}^{a-e}[s \times (Y_j - U_j)] \leq \sum_{j=0}^{a-e} y \times LG_j - \sum_{i=0}^{e} f \times C_i \tag{16}$$

$$Y_j, U_j, C_i, LG_j, LC_i >= 0 \tag{17}$$

Study Case for Optimization Model

The objective of this study was to maximize profits while minimizing land usage and keeping costs as low as possible. The above model is developed to only consider a one-year season; therefore, we can consider it to be a snapshot of how this model will behave in consecutive years. This may be useful in forecasting how much profit can be obtained within any given year. Also, this study only considered Buffel grass, but the generalized model can consider other types of grasses, as well as other crops that can be grown in conjunction such as wheat. Overall, this system is very malleable and can assimilate to many different scenarios that may arise when producing livestock and cattle.

There will be limits to how many cows will be allowed to occupy each acre because of the amount of crop that can be yielded within a time span of 2 weeks. Assuming perfect conditions such as weather and no droughts occurring during the growing season, there will be 2,000 lbs. that will be produced every 2 weeks. However, not all the 2,000 lbs. will be consumed entirely by the cows. This is done to allow for the grass to have stems that will promote growth for future use by the cattle. This can be achieved by implementing a rotational grazing schedule to take advantage of the crop yield that will allow more cows to be able to occupy the entire 54 acres at one time. In addition to a rotational grazing schedule, the 54 acres are divided into two sections: one that has cows grazing and the other allowing Buffel grass to be grown.

Therefore, the objective is to determine the maximum profits while optimizing the number of cows that will be able to occupy each acre of land. To achieve the maximum profit, the aforementioned optimization model using Linear Programing (LP) will be used. The decision variables will be in the form of the loan amount to pay off the irrigation system that will be installed for 54 acres of land. The land will be divided in two to allow for rotational grazing to occur every 2 weeks. The total amount of dry matter feed that each cow will need is 4320 lbs. This model only had 2 cows per acre. The yield is equal to the 1000 lbs. of dry matter that was produced per acre by the number of weeks that the cow resided on it and the 9 months that the season will last. In addition, the selling price was also considered for each cow in the amount of $900.00 U.S. Dollars and the selling price for each pound of dry matter at the current selling rate of $0.08 U.S. Dollars per pound of dry matter feed at the time of this study (TDHR, 2022). However, there will be a difference between how much was consumed by the herd versus how much remained in surplus. Any surplus was sold on the market to contribute to the overall profit. The total cost for the herd is $31345.40 U.S. Dollars or $580.47 U.S. Dollars per cow. However, the total cost for the herd based on the cost being equal to fixed cost + variable costs. Therefore, in this model, only the variable cost will be considered which is 20% of $580.47. The objective is to maximize the total profit, which can be obtained by profits – costs. For the LP model, following decision variables and objective function are used. Lindo will be used as the software to evaluate the linear programming models. The input functions found on table 2 give values for applied model study case.

TABLE 2
APPLIED FUNCTION MODEL VALUES

Input Functions	Values
a	54
n	10
r_2	80%
p	$900.00
σ	$0.08
PV	$70,000
PT	$7998.02

The LP model generated the following result in table 3, based on the input values of table 2. As the cow population increased by one, the overall profit will increase by a value of approximately $60.00. It can be deduced that increasing the number of cows that can reside on a given acre, will help the overall profitability of the system.

TABLE 3
PROFIT IN U.S. DOLLARS FROM COWS

Cows	Profit in U.S. Dollars
54	$29,474.20
55	$29,538.31
56	$29,602.22

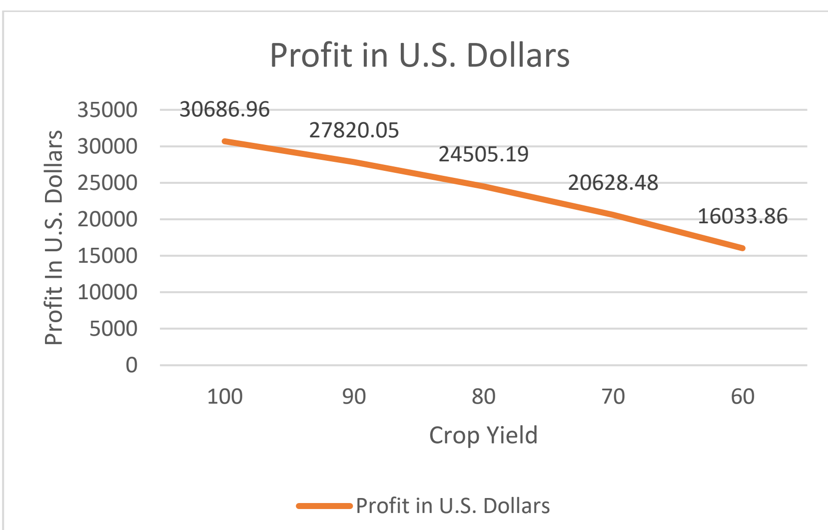
What If Analysis Using Optimization Models

However, the maximum number of cows that can adequately reside on the 54 acres had yet to be determined. Hence, the LP model was then used to maximize the number of cows that can reside within the 54 acres and still be able to sustain themselves in various situations. The amount of dry matter feed yielded incrementally decreased by 10% from a 100% ideal situation. The results shown in table 4, shows that the number of cows will begin to decline with each crop production decrease. However, the model still produced profitable results and was able to maximize the level of cows that resided on that area of land.

TABLE 4
CROP PERCENTAGE YIELD TO OPTIMAL NUMBER OF COWS

Percent Yield (%)	Cows
100	72
90	70.43
80	67.5
70	64.07
60	60

FIGURE 2
PROFIT IN U.S. DOLLARS VS. CROP YIELD



As the percent yield for the crops decreases (see table 4), due to many possible adverse effects such as disease or pest that could occur on the crop production, this in turn causes a decreases on the number of cows that are possible on the dedicated 54 acres of ranch land. In addition, as shown in figure 2, the overall profitability, using LP model, shows a decrease as the percent crop yield declines (see figure 2).

CONCLUSION

A linear programming approach was considered to determine what is the optimal amount of land and cows would yield the highest profitability. Based on data produced by Lindo, the maximum number of cows will be 72 that could reside on 54 acres, this will produce an initial profit of $ 30686.96 U.S. Dollars. This of course will require that all cows reside on all 27 acres at one time. However, as a part of a set of different scenarios, the crop yield was decreased by 10% increments while attempting to find the maximum number of cows that reside on the 54 acres. It was shown that as the crop yield decreased the number of cows would decrease as well as the overall profitability. Therefore, based on the risk factors such as drought or pests this could lead to an overall decrease in profit. Future work that will be considered will be to use this model to determine the forecasting of profitability over a specified time. This will provide data that will help determine the break-even point under various situations and will decide if it is a viable solution to add an irrigation system.

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