PROFIT MAXIMIZING LIVESTOCK PRODUCTION AND MARKETING STRATEGIES TO MANAGE CLIMATE VARIABILITY

BY

SUBRAMANIAN MURUGAN

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"Profit Maximizing Livestock Production and Marketing Strategies to Manage Climate Variability," a thesis prepared by Subramanian Murugan in partial fulfillment of the requirements for the degree, Master of Science, has been approved and accepted by the following:

Linda Lacey
Dean of the Graduate School

L. Allen Torell
Chair of the Examining Committee

Date

Committee in charge:

Dr. L. Allen Torell, Chair

Dr. Brian H. Hurd

Dr. Mark Peterson

Dr. Octavio A. Ramirez

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VITA

May 7, 1978	Born in Karur, Tamil Nadu, India.
2000	B.S. (Agriculture), Tamil Nadu Agricultural University, Tamil Nadu, India.
2003	M.S. (Dairy Economics), National Dairy Research Institute, Haryana, India.
Aug.2003-Mar.2004	Senior Research Fellow, National Dairy Research Institute, Haryana, India.
Apr.2004-May 2005	Research Associate, National Center for Agricultural Economics and Policy Research (NCAP), New Delhi, India.

Field of Study

Major Field: Agricultural Economics

ABSTRACT

PROFIT MAXIMIZING LIVESTOCK PRODUCTION AND MARKETING STRATEGIES TO MANAGE CLIMATE VARIABILITY

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Dr. L. Allen Torell, Chair

The purpose of this thesis was to determine profit maximizing ways to adjust for and manage annual forage variability. Data collected periodically over 17 years from forage production studies conducted on the New Mexico State University's Corona Range and Livestock Research Center (CRLRC) and weather records for the Corona, NM area were used to define production relationships, and to estimate the level of annual variability expected in animal and forage production.

A multi-period linear programming analysis was used to evaluate optimal production and livestock marketing strategies. The Monte-Carlo procedure simulated 4,000 different beef price and production situations. Various drought management strategies such as adapting a flexible stocking rate, purchasing outside forage and leasing forage to an outside yearling operator were evaluated. The mathematical model provides a planning tool for the Corona Ranch that can be used to evaluate the economics of proposed range improvements and alternative management practices. It

also provides insight for optimal production on similar New Mexico ranches.

The current desired base cow herd size of 345 AUY was approximately the profit maximizing number of brood cows to have on the 44 section Corona Ranch. However, maintaining only this cow herd and not adjusting stocking rates upward during favorable production years means relatively low economic returns in good years due to lost opportunity costs.

Any excess forage produced in average or above average years should be utilized by purchased yearling or leased to an outside yearling operator. As stocking rate increased by incorporating flexibility of stocking rate the annual net return increased in variability and in average level. There was found to be a great deal of economic potential to increase ranch returns by adopting flexible stocking rates to take advantage of favorable production years, but at the expense of accepting more production risk. The challenge for southwestern rangelands is accurately forecasting what forage conditions will be over the grazing season when the majority of production does not occur until late in the season when summer rains arrive.

It was generally more profitable to maintain the cow herd through drought periods by leasing outside forage than to reduce cow numbers. If yearlings were added, the least cost adjustment would be a shift from a cow/calf enterprise to yearlings in the later years of the planning period. Overgrazing was not considered as a viable drought management option in the analysis. Instead, herd size was reduced or leased forage purchased to meet annual forage demands, depending on profitability.

The economic viability of range livestock operations is greatly affected by management's ability to cope with climate variability and the ability to judge present and future forage conditions. By forecasting and incorporating rainfall and forage production information into stocking rate decisions, a ranch manager can maximize economic returns and adapt least cost strategies when adjustments must be made because of drought.

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INTRODUCTION

Overview

Rangeland and livestock management in the southwestern United States faces many challenges. Droughts, cattle and feed prices, pest and disease, undesirable brush infestation, and environmental problems are the most important factors that contribute to the management challenges of the range-livestock industry. Although, rangeland and livestock mangers have little control over any of these variables, drought may be the least controllable, and is especially damaging on southwestern ranges where forage production depends largely on the amount of precipitation received during the growing season (Gray et al. 1983).

The economic viability of range livestock operations is greatly affected by management's ability to cope with climate variability. Gray et al. (1983) found that in the past, ranchers have mostly endured drought by reducing livestock numbers, leasing forage, temporarily grazing ranges beyond their capacities, increasing livestock feeding and attempting to offset higher feed costs by reducing other costs where possible. It is widely recognized that rainfall is the primary limiting factor that determines forage and livestock productivity, and underpins decisions related to proper grazing use, herd size, stocking rates, livestock weight gain and ultimately ranch returns and profitability.

Reynolds (1954) reported that annual rainfall was almost entirely responsible for fluctuations in forage yield on southwestern rangelands, and this wide variability in yield is considered to be a major production risk for ranchers. Coupled with drought, if a ranch is also infested with undesirable brush species, annual forage production can be further suppressed. McDaniel et al. (1993) noted that a heavy infestation of broom snakeweed (*Gutierrezia sarothrae*) suppresses annual herbaceous forage production to levels that are comparable to yields realized during drought even when annual rainfall amounts were average and above average. The dual effect of low rainfall and woody plant infestation can greatly limit forage production and increase annual production variability.

With periodic drought and competition with overstory brush species, maintaining an adequate forage supply is problematic. It is also a major expense to reduce herd size frequently and to buy alternative feeds. Further, failing to reduce livestock numbers during drought and overgrazing the range can have long term negative impacts on future rangeland productivity and can also reduce livestock weight gain and productivity.

Drafting drought sensitive grazing strategies and range improvement programs is a herculean task for rangeland managers. Improving these decisions starts with a basic understanding of rainfall patterns, drought frequency and intensity, and how rainfall events are related to forage and animal production. By knowing and incorporating this information into stocking rate decisions, ranch managers can maximize economic returns and adopt least cost strategies when adjustments must be made because of forage shortfalls.

Study Objectives

Rainfall is variable and unpredictable and as a result, forage production is variable and unpredictable. The objective of this research is to determine profit maximizing ways to adjust to this variability including alternative livestock marketing strategies, herd reductions and/or feed purchases with the accompanying expense. A profit-maximizing multi-period linear programming model is used to estimate optimal adjustments with variable annual forage production and beef prices. The model is developed using the resources and production characteristics typical of a ranch in the Pecos-Canadian Plains and Valleys in central New Mexico, following the land classification of the Natural Resources and Conservation service (NRCS) (USDA-SCS 1981). Specifically, forage production studies conducted on the New Mexico State University's Corona Range and Livestock Research Center (CRLRC) and weather records for the Corona, NM area are used to estimate the level of variability expected in animal and forage production. The multi-period model considers the production rates and resource base specific to the CRLRC, though this working research ranch is not unlike other commercial ranches found in the area.

Thesis Design

After reviewing the literature about the impacts of drought on annual forage production and animal performance, and previous drought planning models, the resources of the CRLRC are described along with studies conducted on the Corona Ranch that formed the basis for defining expected forage variability on the ranch. The multi-period linear programming model is described in detail along with key economic variables and assumptions used to define the maximization model. Using the model, various drought management strategies are explored including alternative ways of marketing livestock, adapting flexible stocking rates and herd size, and the economic potential of replacing forage shortfalls with purchased feeds.

LITERATURE REVIEW

Drought Effects on Animal Performance

Smith and Foran (1992) investigated the economic effects of alternative destocking tactics in the face of drought for a sheep enterprise on semi-arid rangelands in South Australia. The strategy of taking no action and of destocking the herd of 14,600 sheep by 20 percent and 40 percent as soon as seasonal rainfall failed to materialize was considered. By examining all possibilities over a ten year sequence of good, average and drought years, a strategy of substantial destocking was shown to have better long-term expected economic returns. This resulted because high stocking rates could precipitate nutritional problems earlier in dry times than what would happen on lightly stocked pastures. Continued heavy stocking rates ultimately lead to rangeland degradation.

Buxton and Smith (1996), in their study in NW Queensland, Australia, compared different tactics of destocking to estimate the financial implications of alternative approaches during drought periods, and found that subtle adjustments to one tactic could make substantial differences in financial outcomes. They compared the tactics of selling all steer weaners during drought with selling the same number of steers, but from a cross section of age groups. These two selling methods were simulated over a period of ten years consisting of two average rainfall years, two drought years, and then six years to rebuild the original pre-drought stock numbers. At the end of the ten years, the accumulated cash balance for selling the same number of steers across age groups was 10 percent greater than selling all steer weaners.

Similar studies were also conducted on properties in other regions of Australia. It was consistently found to be economically advantageous to retain breeding animals where possible and to retain stock which would be saleable immediately after the drought, and sell stock with the lowest levels of productivity.

Buxton and Smith (1996) also examined two ways of rebuilding stock numbers after drought to estimate the profitability of alternative approaches by comparing a slow buildup with ranch raised animals with a faster buildup by purchasing breeding animals. With the faster buildup, it took only two years for breeding animal numbers to return to pre-drought levels, compared to four years for a slow buildup. After five years of prolonged drought, faster buildup had an accumulated cash balance that was 10 percent higher than the slow buildup option. But, despite the added profit many producers felt that slow buildup after drought was better for the land, and would thus give long term financial benefits.

Martin and Cable (1974) recommended a constant stocking rate at or below 90 percent of the average long term carrying capacity, with appropriate reductions during prolonged severe droughts. They developed the 90 percent stocking level recommendation during a 10 year study where cattle utilized 40 percent of the available key forage production, and left behind approximately 60 percent of the annual production as residual vegetation. The 40 percent utilization level resulted in improved range condition, economic stability and permitted a gradual increase in stocking rates.

Silvey et al. (1978) examined the value of perennial tropical pastures for breeding cows over a period of five years (1968-1973) on semi-arid fertile brigalow clay soils at the Narayen Research Station in Queensland, Australia. The included pastures species were Guinea grass (*Panicum maximum)* grown alone or with legumes like Siratro *(Macroptilium atropurpureum)* and alfalfa *(Medicago sativa).* They found a strong interaction between stocking rates and pasture production, which significantly affected the time of conception, and conception and calving rates. The pastures were rotationally grazed at different stocking rates both with and without fertilizer application. When the stocking rate was increased from 0.87 to 1.75 cows/ha, the loss of cow liveweight increased from 5 kg to 84 kg, and reduced conception rates to 68.5 percent from 100 percent.

Bement (1969) built a stocking rate guide keying on animal gain per acre and animal daily gain in relation to ungrazed herbage remaining at the end of the grazing season. He reported that light stocking rates resulted in high animal daily gains but low animal gain per acre, whereas moderate to heavy stocking rates resulted in low animal daily gains but high animal gain per acre. The maximum average gains of 16.8 kg/ha was obtained at a stocking rate of 0.89 ha/yearling month when approximately 280 kg/ha of air dry herbage were left at the end of the grazing season. The maximum average daily gains of 0.65 kg/animal were achieved by leaving at least 392 kg/ha of herbage at the end of the grazing season. When 336 kg/ha of herbage was left ungrazed, animal production per ha was at a maximum and herbage production was not negatively impacted. Leaving this amount of herbage was recommended as a stocking rate prescription.

Hart et al. (1988a) studied steer performance at the High Plains Grasslands Research Station (HPGRS) near Cheyenne, Wyoming with different grazing systems and different stocking rates. They found that with high stocking rates, average daily gain (ADG) was higher with rotational grazing than with a short duration grazing system. The lower ADG was attributed to the fixed schedule of rotation, resulting in overgrazing of some paddocks and under use of others, instead of adjusting grazing according to forage supply and plant growth rate.

ADG of steers remained high and constant at low stocking rates, and then declined at high stocking rates because of varied forage production among years. Stocking rate was expressed as grazing pressure (GP) or steer days per metric tonne of forage dry matter produced (Hart et al. 1988a). This measure of grazing use was considered advantageous because it recognized production differences resulting from both increased stocking rates and decreased levels of forage production. Animal gains were found to remain constant at 0.95 kg/head/day until grazing pressure exceeded 29 steer days/tonne of forage, and then started to declined by the linear equation, ADG = 1.13-0.00625 GP, $r^2 = 0.66$. Any differences between grazing systems were attributed to differences in grazing pressure. Manley et al. (1997) extended the grazing trials at the HPGRS through 1994 and similarly concluded that ADG declined linearly with GP (ADG=1.06-0.00527GP, r^2=0.44) and with no differences between continuous, rotationally deferred and time controlled grazing strategies.

Hart and Ashby (1998) studied at the Central Plains Experimental Range (CPER) near Nunn, Colorado and also found that ADG decreased linearly as GP increased, using the regression equation ADG = 0.787 - 0.00364 GP, (r^2=0.45). GP accounted for slightly less than half of the variation in gain with the remaining variation explained largely by factors such as breed, initial weight and body condition of the cattle, inter and intra year variation in nutrient concentration in the forage, weather and health related stresses in the cattle.

Hart et al. (1988b) reported that live weight gains of lactating cows, yearling heifers, and calves declined linearly with increasing grazing pressure (GP). On dryland crested wheatgrass pastures, critical grazing pressure was estimated to be approximately 40 animal-unit days (AUD) per tonne of forage dry matter produced. When GP was below the critical grazing pressure, cow, heifer, and calf liveweight gains remained constant at 1.27, 1.16, and 0.97 kg/day, respectively but on brome alfalfa, above the critical GP, gains declined linearly with increasing grazing pressure. Gains were higher on crested wheatgrass at an intermediate GP but higher on brome-alfalfa at high and low GP. Since calves received most of their nutritional needs from milk, calf gains decreased very slowly with increasing GP, but cow gains declined sharply with increasing GP because of the nutritional demands on the cow for milk production. With the highest grazing pressure, cows lost weight even though they were fed with high quality crested wheatgrass and brome-alfalfa grass. Maximum gains of calves were nearly the same on native rangeland as on crested wheatgrass but lower on both compared to brome alfalfa pasture (Hart et al. 1988b). Cow gains again declined sharply with increasing grazing pressure above critical GP and cows lost weight at the highest grazing pressure. The response of conception rate to grazing pressure followed the same pattern as live weight gain. In the case of brome alfalfa, the conception rate was 100 percent below the critical grazing pressure of 41 AUD/tonne of forage produced and then declined linearly with further increases in grazing pressure.

Reynolds (1954) studied the effect of climate variation upon perennial grass yield and animal production on Foothill pasture on the Santa Rita Experimental Range in Southeastern Arizona and Southwestern New Mexico using data collected from 1921 to 1951. A pasture comprised of 70 to 85 percent Black grama grass (*Bouteloua eriopoda*) and a conservative stocking approach was used. During a slight drought, no stocking reductions were necessary. In moderate drought, the stocking rate was reduced to below average whereas in severe drought, the stocking rate was reduced to 60 percent of average. When stocking rate was conservative and an adequate quantity of forage was available for feeding, drought had little effect on calf live weights, and with minor exceptions, herd reductions were sufficient for proper nutrition and maintenance of calf weights during all drought periods. Following the later developed grazing pressure concepts of Hart, GP was adequately reduced during the drought periods so as to have minimal impact on animal performance.

Bedell and Ganskopp (1980) studied severe drought occurrences and their effects on range, cattle, and management in the Pacific Northwest, east of the Cascade Mountains. When a severe drought occurred in 1976-77 many cows delayed their breeding until late summer or fall, which ultimately lead to reduced calf crops in 1978 or greatly spread out the calving season. Because of shortage of green feed availability for lactating mothers, the later born calves never gained liveweight to levels comparable to early calves. As a result, drought years not only meant fewer calves in the following years, but calves also gained less weight and weaned lighter. If drought occurred for one year it was found to cause delays in calving and it was difficult to get the cow back on schedule in her productive lifetime without skipping a year. Bedell et al. (1980) estimated it required at least 4-5 years to get a cow back on schedule in the production process.

Ash et al. (2000) described three different grazing management approaches in the Dalrymple Shire of northeast Queensland, Australia that are commonly used to cope with drought. They concluded that instead of overgrazing, animals should be fed supplements or moved to alternative forage sources when possible. This method was preferred by many producers because production per ha was maximized at high stocking rates in the short to medium term (3-10 years). Ranchers believed that maintaining high stocking rates was considered financially rational even when supplements and leasing forage costs are taken in to account. In the long run, however, financial and resource management implications of the high stocking rate strategy were less known from empirical studies, but by using the forage-animal production model GRASP, it was estimated that a series of dry years would force down perennial grass production, from which the system did not recover. Production was greatly diminished and soil loss increased dramatically.

A second approach studied by Ash et al. (2000) was conservative stocking designed to utilize some safe amount of forage growth to minimize drought impacts on the ranch. This strategy will over-utilize forage resources and create feed shortages in extremely dry years but it was recognized that such dry seasons will be infrequent. Although this strategy's production per unit area was found to be low relative to heavier stocking rates, it had the advantage of maintaining and improving the forage resource, minimizing production costs, and maximizing individual animal performance. Because this strategy does not adjust stocking rates upward during favorable production years, the conservative stocking approach received relatively low economic returns in good years due to lost opportunity cost, but in poor years it outperformed other strategies due to lower cost and better animal performance. An added advantage of this strategy was with increased fuel loads during favorable years fire could be used to control the increase in unwanted woody plants.

Ash et al. (2000) described a third grazing strategy as adopting stocking rates in a flexible way by responding to changes in available forage supply. This strategy assesses the availability of forage at some fixed point in the season when further rainfall was unlikely. It requires considerably better herd management and marketing skills because an error in judgment will lead to sudden and serious consequences for ranch economics and the resource base. This method outperformed the conservative stocking as it more fully utilized resources during good years but avoided the economic and environmental costs of overstocking by reducing stock numbers during forage shortages. The GRASP model estimates showed that the flexible grazing strategy had an 18 percent production advantage (kg of beef production) over the constant stocking strategy, and the relative benefit of adopting this approach increased as rainfall variability increased. Economic benefits were not compared.

A similar flexible strategy was recommended by Dahl (1963). He reported that many grazing programs aim to minimize the effects of wide forage fluctuations caused by variation in precipitation. He described a common recommendation to be stocking the range with a core breeding herd that is set below what would be detrimental to the range during drought years. Any excess forage produced in average or above average years would be utilized by purchased animals or by carried over yearlings. Further, Dahl (1963) noted that a reliable method for predicting forage production in advance of the grazing season could have great value in implementing a ranch protecting grazing program.

Drought and Grazing Effects on Forage Production

In addition to animal performance differences, Reynolds (1954) also studied the relationship between total forage production deviation from average and the summation of successive departures of rainfall from average for 30 years. He plotted the relationship, and the graph showed a curvilinear relationship between loss in forage production and drought periods. The forage loss occurred at an increasing rate as rainfall increasingly deviated below the mean. He also noted that a small annual deficiency in rainfall for a long series of years had an effect similar to the effect of a large annual deficiency over a shorter period. He stated that severity of drought was a combination of the amount of rainfall deficiency for any year and the number of years in succession in which rainfall remained below average.

Heitschmidt and Vermeire (2006) reported that summer production capacity of the grasslands in the Great Plains region, following spring drought, would be quite limited because of a general absence of productive warm-season perennial grasses. Warm season perennial grass production with ample summer rainfall was essentially the same as that of an average, non-drought year. High rainfall in the summer did not enhance annual production levels to offset production loss resulting from spring drought. In addition, the quality of forage varied in direct proportion to the relative amounts of live and dead tissue, which in turn varied largely as function of amount of precipitation received.

Holechek (1996) examined the historical climatic records for New Mexico and reported that the state had severe extended drought lasting 4 to 6 years once every 40 years. He attributed the 1996 drought to the "La Niña - El niño cycle". After the extended drought period, even with above average rainfall and good grazing management practices, forage production was only about half of the 10 year average (Herbel et al. 1972). This was because of death and weakness in primary forage grasses, and the five to seven years required for full rangeland recovery from severe drought. Rangelands grazed conservatively or moderately produced more forage during drought than those heavily grazed, and recovered more rapidly after drought (Klipple and Costello 1960, Paulsen and Ares 1962).

Holechek (1996) suggested New Mexico ranchers should reduce the breeding herd by 35-50 percent when drought becomes apparent. Holechek agreed with the assessment of Boykin et al. (1962) that reducing livestock in accordance with forage availability rather than holding livestock and providing them harvested feeds was the best option because harvested feed costs more for ranchers to purchase while at the same time cattle prices declined because of drought.

Teague et al. (2004) measured herbaceous and bare ground changes on adjacent heavily grazed and lightly grazed patches in rotationally managed pastures as compared to adequately rested pastures and continuously grazed pastures in the Rolling Plains of North Central Texas on the Waggoner Experimental Ranch. They reported that deterioration of herbaceous cover during periods of extended drought proceeded at a relatively slow rate. Although rotational grazing did not prevent deterioration in grass basal area and increased bare ground with a series of drought years, it did decrease the rate of deterioration and the authors found that in large paddocks rotational grazing can reduce rangeland deterioration and allow improvement of both short grass and mid grass patches.

Smith and McKeon (1998) worked with the GRASP pasture production model to assess the historical frequency of drought occurrence for rangelands in North Queensland and western New South Wales, Australia. The daily observation of actual weather elements, and reconstructed data (for missing observations) for more than 100 years was used in the simulation model. They modeled a constant stocking rate (consistent stocking rate between years) and reactor strategies (buy and sell each year to maintain a consistent level of forage utilization). They simulated ten different target levels of stocking rate for a North Queensland 20,000 ha pasture to develop response curves of economic output against stocking rate. A target level of 1,750 cows for the constant strategy, and 20 percent forage utilization for the reactor strategy resulted in an optimum economic condition. By comparison, in the case of the SW Queensland 34,000 ha pasture a target level of 9,000 ewes for constant, and 20 percent forage utilization for the reactor strategy was found to be optimal.

Koc (2001) estimated the effects of drought at the natural rangelands of Ataturk University in Erzurum, Turkey, between September 1996 and July 1998. The research was conducted with sheep fescue (*Festucaa ovina* L.) on sandy loam soils. He found that when plants entered winter without autumn regrowth because of drought, the reproductive shoot numbers were reduced to 31 m^{-2} from 617 m^{-2}. Koc (2001) further noted that the autumn drought imposed plot recorded 424 kg/ha aboveground biomass with 1.5 water use efficiency (WUE), whereas the plot receiving normal autumn rainfall in addition to 40 mm of added water produced 1,038 kg/ha aboveground biomass and 2.4 WUE. With short term drought in the spring the aboveground biomass production was increased, but WUE was decreased. Koc (2001) observed that autumn drought had no effect on the proportion of grasses, but reduced legumes. The spring/summer drought had no effect on legumes but, as the onset of drought was delayed, grasses decreased and other species increased in composition. The autumn drought reduced canopy coverage from 35 to 24 percent but spring drought had a negligible effect, thus, he concluded that autumn precipitation was crucial for productivity of high elevation rangelands.

Drought Effects on Net Economic Return

Workman and Evans (1996) applied linear programming optimization methods to study the optimum intensity and mix of improvements to offset the most limiting resource constraints and to simultaneously measure the combined impacts on total ranch net returns. The research was conducted based on production and economic data for a typical Utah ranch based on detailed surveys of 96 Utah cattle ranches. The typical Utah ranch ran 196 brood cows and replaced 14 percent of the cows annually. They identified that May forage was the limiting constraint on optimum herd size and net ranch income. The LP shadow price for May forage was found to be $179 per AUM and at this high level several range improvements were economically feasible.

Gray et al. (1983) reported that drought was a major problem on New Mexico rangelands and had serious repercussions on herd size, cost and returns. In a survey of producers, livestock numbers were reduced from 14 to 41 percent, with the higher reduction on the larger ranches. The reductions were especially great on heifer calf numbers, heifer yearling numbers and cows. On larger ranches, steer calf and yearling reductions exceeded those of heifer reductions. On sheep ranches, herd reductions were made mostly with aged ewe animals. Calving percent reductions generally were greatest on the larger ranches, ranging from 6 percent on small ranches in the northwestern and northeastern areas to 15 percent on large ranches. While the largest ranches had the largest reductions in receipts per ranch (41 to 64 percent), the medium sized cattle ranches had 28 percent, and the reductions appeared to be more closely related to ranch size rather than to ranching areas.

Gray et al. (1983) further noted that with drought feed costs increased sharply on most ranches (> 40 percent). The percent increase in cost due to drought was not related to ranch size. However feed cost were usually 15 percent or less of total cost on most ranches during non-drought years and reducing cattle numbers saved these costs. Net returns declined mostly on small ranches during drought years and least on extra large ranches. However even on the largest ranches, net return declined by 75 percent or more. Larger ranches apparently had more flexibility in adjusting to drought than smaller ranches, and ranches with two or more enterprises, either cow-calf-yearling or combination of sheep and cattle, were more flexible than single enterprise ranches and were more able to survive drought years. Market weights were a consistently important factor affecting receipts, although on a percentage basis they were less important than the need to reduce herd size. Ranchers in southwestern New Mexico were judged to have the most experience with drought and were found better able to adjust to drought as compared to ranches in other areas of the state.

Drought Planning Models

Davidson (1991) described a computer program, RANCHPACK, for testing the effect of different rural development programs by rangeland managers and pastoralists in Australia. This micro computer assessment program was used to estimate a range of strategies such as long term property development programs and short term responses to problems like drought and fluctuating livestock prices. Costs and financial returns were simulated for a herd and the outcome could be compared based on the herd's response to good, average, poor, and drought years.

Jackson (1998) reported that, as part of the national drought policy in Australia in 1992, the Centre for Agricultural and Resource Economics at the University of New England, Armidale developed a simulation model, RISKFARM, to examine the options for strategic investment in reserves to assist in managing through periods of drought, while accounting for other common risks. The main purpose of developing the model was to estimate the financial and risk effects of drought by allowing variation in economic and biological parameters. The effect was estimated by the RISKFARM model by utilizing the probabilistic @RISK spreadsheet software. It is a whole farm stochastic budgeting program, which allows uncertainty represented through probability distributions for selected variables in the operating environment and captures risk by generating probability distributions for nominated final outcomes. This model used physical and financial data provided by farm and ranch managers to assess the financial, and risk effects of alternative farm and non-farm products, and investment decisions. The stochastic variables considered for the RISKFARM model included yield, prices, expenses, interest rate, mortality rate, and weaning rates.

The weakness of RISKFARM was stated to be that it is not a bio-economic model or optimization model but rather a stochastic simulation model (Jackson, 1998). Hence, it was not possible to use the model to predict behavioral response to climate variation and market conditions. Although, RISKFARM does not directly capture the environmental impacts of drought, these impacts can indirectly be captured by making assumptions about associated impacts on yield and price distributions.

Seasonal Climate Forecasts

Ash et al. (2000) worked with five forecasting techniques namely, the Spring Southern Oscillation Index (SOI), SOI Phases, spring SOI (spring SOI average and SOI phases), Winter Pacific Ocean Sea Surface Temperature (SST), and Winter Pacific and Indian Ocean SST to manage climate variability in the Dalrymple Shire of northeast Queensland, Australia. They used the forage-animal production model called GRASP to assess different climate forecasts on constant and flexible grazing management systems. These forecasting systems were lagged forecasts based on observed values of either SOI or SST. The forecast indices were also based on historical rainfall records for nine rainfall stations and were classified into three year period of different types such as above average, average and below average.

The spring SOI forecast gave the best prediction of liveweight gain per unit area (ha) for a constant stocking strategy applied in June, while a local SOI forecast gave the best prediction when a constant stocking strategy was applied in November. For the flexible stocking rate strategies, the SOI phase forecast was the most beneficial in both June and November. The SST forecasting systems consistently produced less benefit than the SOI based forecasts. Researchers also noticed that even without forecasts, the flexible grazing strategy produced significant improvement in production and at the same time reduced soil loss as compared to a constant grazing strategy. When a forecast was applied to a flexible grazing strategy, the additional benefit was relatively small. Pastoralists accepted the constant grazing strategy with a seasonal climate forecast to a greater extent because it was easier to apply.

Ash et al. (2000) said that there was considerable spatial variation in the benefit among the forecasting methods, but within the forecasting method, the spatial differences in the value of a forecast were reasonably consistent across stocking strategies and timing of stocking rate changes. They found that though 59 percent of the producers had shown an interest in SOI, only 8 percent of the producers used seasonal forecasts and the remaining producers wanted to see the reliability of the forecast before applying it. With a proven reliability, 70 percent of the producers indicated an interest in using forecasts, and would likely take appropriate actions to reduce stocking rates in dry years and increasing it in wet years.

Jochec et al. (2001) studied factors affecting the use of seasonal climate forecasts in ranching enterprises and estimated the economic value of seasonal climate forecasts by using a biophysical-economic model in West Texas. The PHYGROW model used daily weather data for Sonora County, Texas from 1949 to 1998 for soil, plant, and herbivore inputs to simulate livestock and forage production. The resulting animal production, stocking rate, weaning weights and calf crops were then used to model the ranch economic and forage production situation. Forage-production forecasts were based on forage deviations from the long term average. Daily deviation was calculated from the long term daily average and summed for each year. When the yearly deviations were greater (less) than the mean yearly deviation plus (minus) one-half standard deviation of the yearly deviations, then it was classified as above (below) average. Approximately, 24 percent of the years fell in the above average category, whereas 45 percent, and 31 percent of the years fell into typical, and below average years of production. Jochec et al. (2001) also found that ranchers felt weather was the single most important factor to their ranch business, and forage production forecasts was one of the many factors influencing their decisions. The ranchers used conservative approaches to manage drought conditions and reacted to forecasts only in poor conditions rather than favorable conditions. The stocking rate was decided by current and previous year range conditions and feed and livestock prices rather than the climate forecast information.

Jochec et al. (2001) calculated the expected value of a seasonal forage production forecast per section for different scenarios including various destocking prices against restocking prices (set at $700/cow). They concluded that the value of forecast information depends on changes in stocking rate that affect number of calves sold, time of calf sales, variable costs, revenue, and costs associated with the buying and selling of cows.

MATERIALS AND METHODS

Study Site

This study was conducted at the New Mexico State University's Corona Range and Livestock Research Center (CRLRC), near Corona, New Mexico. The research center functions as a working laboratory for faculty members and graduate students of the Department of Animal and Range Science, New Mexico State University. Research activities are incorporated into the ranch's normal production of cattle and sheep.

The Corona Ranch is located approximately 186 miles northeast of Las Cruces, New Mexico, and 8 miles east of the village of Corona. The ranch approximately covers 28,112 acres (11,381 ha) in the north central part of Lincoln County and southeast corner of Torrance County. The ranch has been used for sheep and cattle production since it was established as an NMSU research center in 1988. The climate of the ranch and surrounding area is characterized by a semiarid, continental climate with wide ranges in diurnal and seasonal temperatures and with plentiful sunshine and relatively low precipitation which averages 370 mm annually. Approximately 70 percent of annual precipitation occurs from May to October as a result of high intensity, short duration, and convectional thunderstorms (Forbes and Kelly, 2001).

The Corona Ranch lies in the Great Plains geologic province. The general prevailing topography of the ranch includes gently rolling hills alternating with undulating to flat plains with limestone sinkholes characteristic of Karst topography, sand dunes, and steep rocky mesas and outcrops (Forbes and Kelly, 2001). The elevation of the ranch is approximately 1,860 m (6,100 ft) (Majumdar 2006).

The Corona Ranch had a livestock inventory of 255, 282, and 303 total animal units yearlong (AUY) in 2003, 2004 and 2005, respectively. In 2005, the livestock inventory was estimated to be 88 percent of a desired base of 345 AUY (Unpublished data, Corona Ranch, Advisory Committee Meeting, 2006). The total AUY were relatively low in these years because of drought from late 1999 through 2003. The ranch was largely destocked in 2001 (Torell et al. 2007). Over this period sheep production on the ranch was about 23 percent of the total AUY. The current (June 2007) inventory of cattle and sheep on the Corona Ranch is very close to the desired base herd of 345 AUY with 194 mature cows, 86 replacements, 74 yearling replacements, 10 bulls, 6 horses, 248 ewes, and 38 goats for 332 AUY.

Corona Ranch Weather Data

Because annual variation in forage production is so closely tied to annual variation in growing season rainfall and soil moisture a detailed analysis of weather patterns on the Corona Ranch was required. Weather data for the Corona Ranch are available from multiple sources including 4 instrumented weather stations and eight rainfall gauges scattered at various locations across the ranch (Torell et al. 2007). Two automated weather stations served as the primary data source for this study and are located at two study sites on the Corona Ranch where grass and snakeweed yield data were also collected. These study sites, referred to as the “Oil Well” and “South House” research sites, were established in 1990 by Dr. Kirk C. McDaniel, a faculty member in the Department of Animal and Range Science at NMSU. The 8 ha enclosed study sites were established to study the effect of snakeweed infestation on blue grama grass production and were supported with Campbell Scientific Instrumented weather stations and CR-10 multi-port data loggers. Majumdar (2006) provides a detailed description of the weather data collection procedures and database. Figure 1 summarizes recent annual rainfall totals collected for the Corona Ranch. Figure 2 expands to include annual rainfall totals for the Corona area going back to 1914. These data were used to relate grass yield to rainfall conditions as described below.

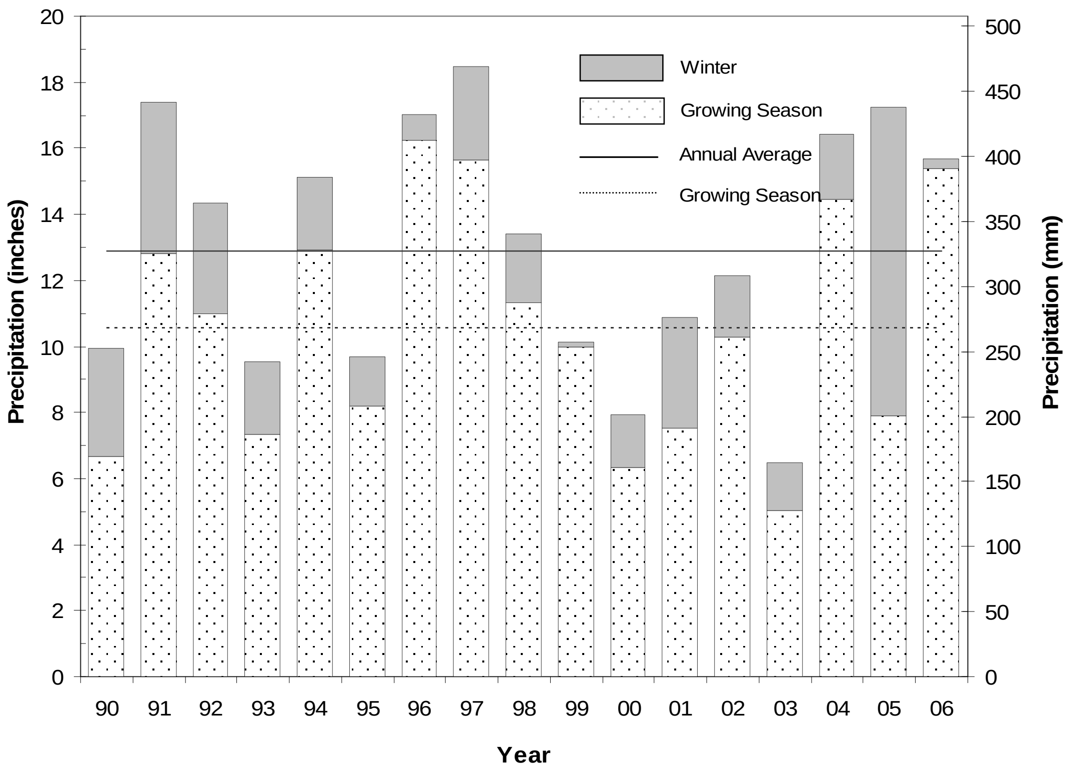
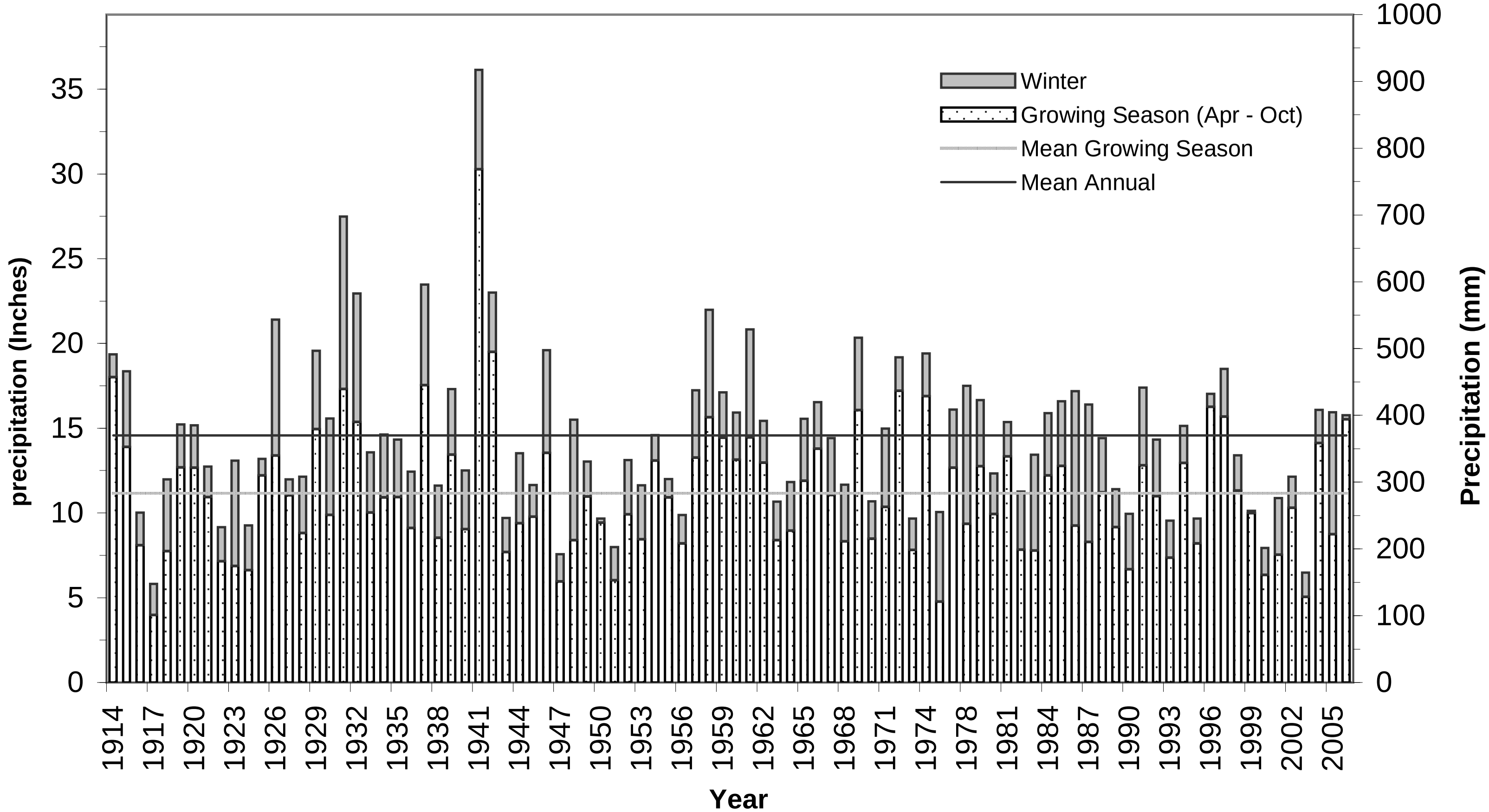


Figure 1. Average annual and growing season (April - October) rainfall recored at the SH and OW research sites (Jan. 1990 - Dec. 2006)



Note: Data for 1977 was incomplete and not included.

Figure 2. Average annual rainfall recorded at the Corona Ranch from 1914 - 2006.

Grass and Snakeweed Production Data

Estimation of expected grass yield variability was conducted using weather data, grass yield data, and snakeweed production data collected from the Oil Well and South House research sites over the period of 1990-2006. Hart (1992), Carroll (1994) and Ebel (2006) provide detailed descriptions of the grass and snakeweed yield data collection procedures, research plots, and the burning and herbicide treatments included in various field studies. Majumdar (2006) provides a detailed listing of grass and snakeweed yield estimates by year, site, treatment, and plot, excluding 2006 data which was recorded at a later date. This study considers only control plots and those plots treated by herbicide spraying.

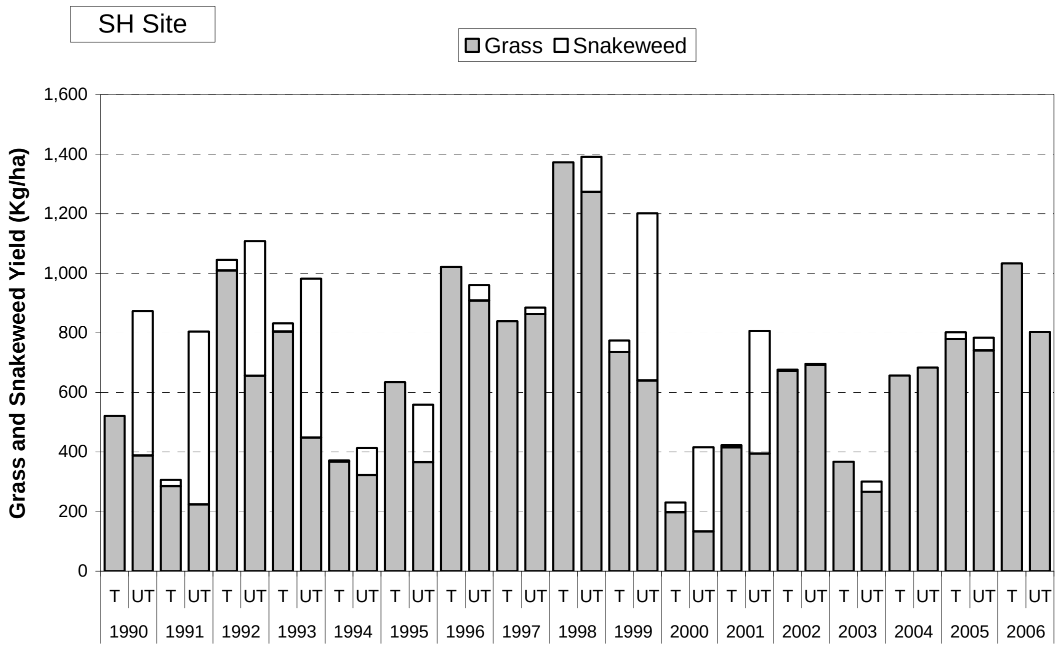
When snakeweed control studies were initiated at the Corona Ranch in 1990, the density and population of snakeweed infestation at the Oil Well and South House sites were considered to be detrimental to blue grama grass production (Hart 1992). The herbicide treatments at these sites resulted in an immediate reduction in snakeweed yield and increased grass production. As the field studies progressed, however, snakeweed yield in the untreated areas also declined because of natural mortality. Snakeweed yield was generally low on both treated and untreated areas after 1993.

Standing crop yield estimates were made each year from 1990 through 2006 from mid October to mid November. The end of season yield estimates does not capture total grass production. Peak standing crop for blue grama rangelands is estimated to occur earlier in the year in August or September, and while variable, peak estimates will be 30 to 40 percent more than the end of the season estimates presented in Figure 3. If left ungrazed for harvesting during the following spring, grass yield will decline an additional 10 to 25 percent from insects, wind and the natural deterioration of leaves and inflorescences during the dormant season (Turner and Klipple 1952, Pieper et al. 1974). Also note that standing crop yield estimates may also capture some of the prior year's vegetative growth because the enclosed study sites were not grazed by livestock over the study period. The study plots were, however, grazed by deer, rabbits, rodents and insects. As noted by Ratliff et al. (1962), plant material lost to insects, trampling and natural deterioration are lost productivity and that cannot be accounted for, resulting in a source of bias in yield estimates.

Grass yield estimates measured from the plots varied from year to year (Figure 3), primarily in response to rainfall that was available over the growing season. Grass yield estimates declined dramatically in 2000 through 2003. The decline in grass production was directly attributed to drought conditions over this period.

Rainfall Frequency Distribution

As noted by Sneva and Hyder (1962), precipitation frequency distributions for semiarid and arid regions are usually not normally distributed but instead show a right skewness. Using a re-parameterization procedure that expands the normal probability distribution by two parameters to incorporate skewness and kurtosis and to allow these parameters to vary as developed by Ramirez and McDonald (2006), Torell et al.



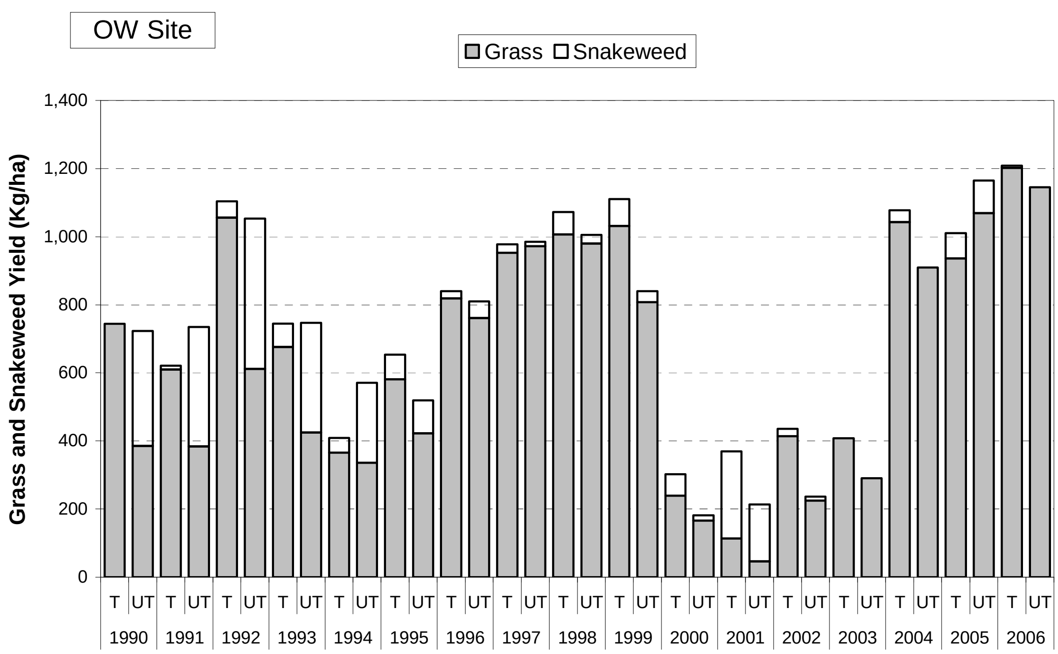


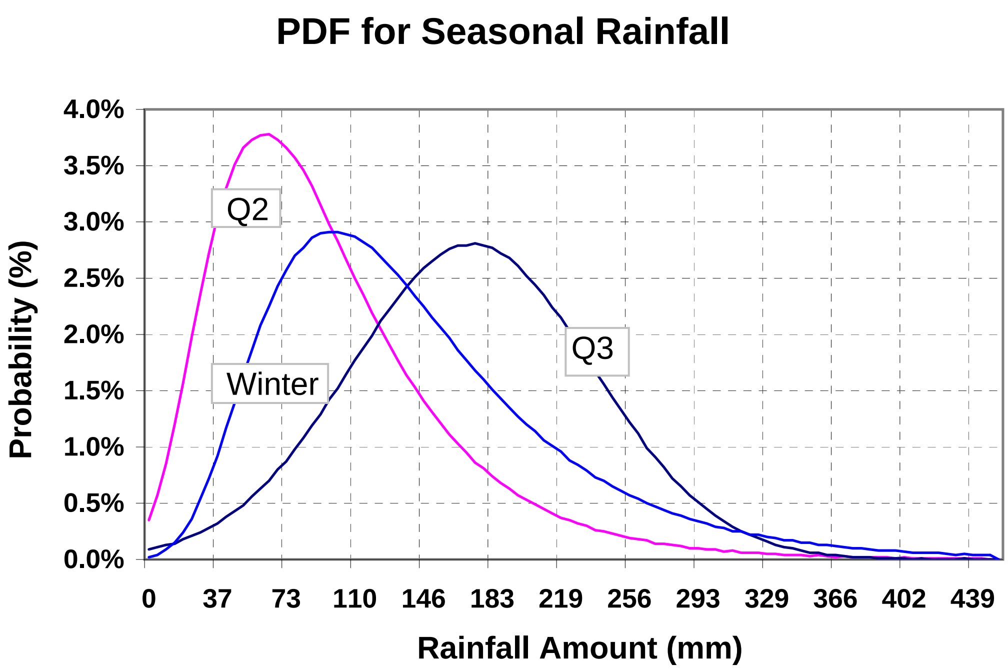
Figure 3. Average annual grass and snakeweed yield (kg/ha) measured on herbicide treated (T) and untreated (UT) areas on the SH and OW sites, 1990 -2006.

(2007) reported similar skewed results for the Corona Ranch. Using the long-term rainfall data shown in Figure 2 it was estimated that rainfall on the Corona Ranch during the winter and quarter$_2$ (Q_2) were right skewed (Figure 4), suggesting a relatively high proportion of the probability curve lies under the right tail. It was found that Q_2 rainfall was above the 76 mm (3 inch) mean level 57 percent of the time. Based on a likelihood ratio test, Q_3 rainfall was not found to be statistically different from a normal curve (P=0.31).

Grass Yield Distribution

Utilizing simulated rainfall data to broaden beyond the 92 years of rainfall data available for the Corona area it was determined that grass yield on the Corona Ranch is related to rainfall and the amount of broom snakeweed present on the area and that average yields are approximately normally distributed with a mean of 768 kg/ha and a standard deviation of 200 kg/ha. This assumes no snakeweed is present on the area. Torell el al. (2007) estimated the functional relationship between annual grass production and seasonal rainfall using ordinary least squares regression and this equation with additional simulations formed the basis for estimating the expected distribution of mean grass yields on blue grama dominated areas.

Since the blue grama grasslands on the Corona Ranch was severely infested by broom snakeweed until 1993, snakeweed yield (kg/ha) was included in the model as an explanatory variable in natural log form. Torell el al. (2007) considered Q_4 rainfall of the previous year and Q_1 rainfall of the current year as a combined winter rainfall variable. Grass yield (kg/ha) was estimated to be a function of Q_2 rainfall, Q_3



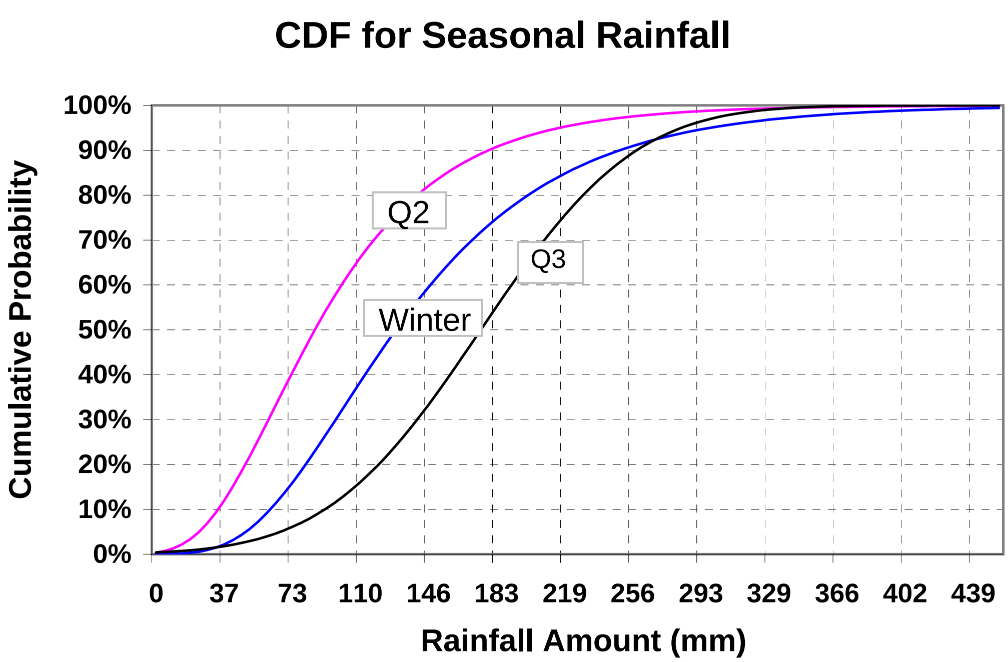


Figure 4. Probability Density Function (PDF) and Cumulative Density Function (CDF) distributions for seasonal rainfall on the Corona Ranch.

rainfall, winter rainfall and snakeweed yield using the regression equation, Grass yield = $\beta_0 + \beta_1 Q_2 + \beta_2 Q_3 + \beta_3$ WINTER + β_4 LNGUSA + ε.

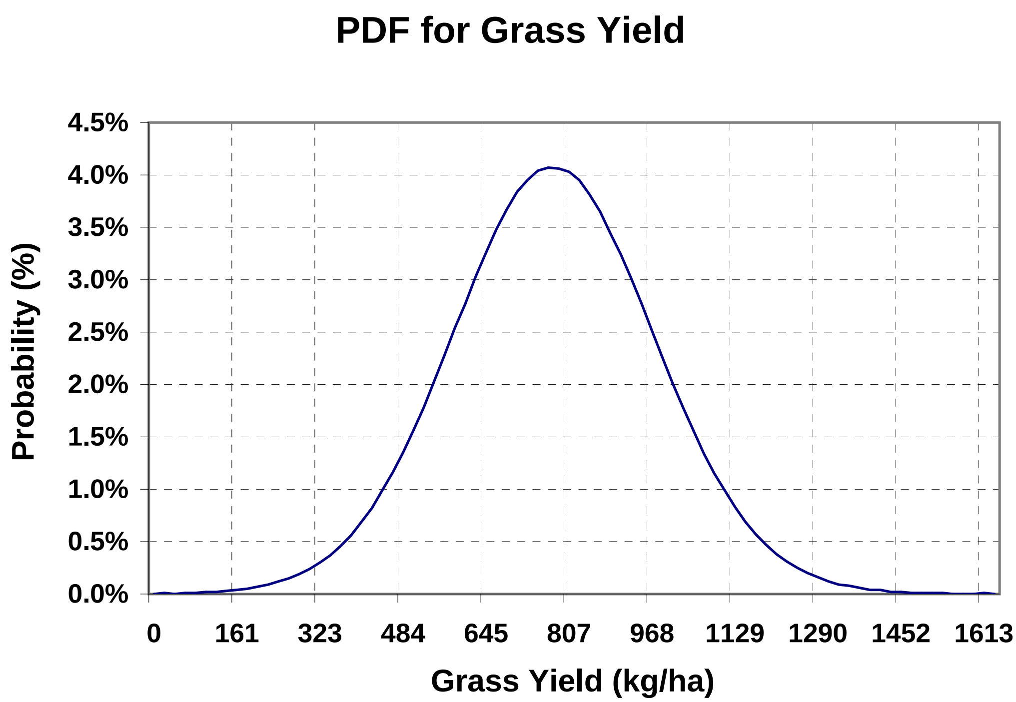
Parameter estimates are shown in Table 1. The analysis indicates that a normal curve or standardized normal table can be used to estimate the probability of forage growth on the Corona Ranch during any particular year (Figure 5). Following the logic of the grass yield equations, the variability in grass yield is attributed to annual variability in seasonal rainfall patterns, snakeweed infestation, and a random component.

Table 1. Regression equation for estimating grass yield as a function of quarterly rainfall and level of snakeweed infestation.

Para-meter	Variable	Mean ± Std	Variable Description	Parameter Estimate	Standard Error	t-value
β_0	Intercept		Model intercept	129.88	37.18	3.49
β_1	WINTER	91.1 ± 68.6	Amount of rainfall (mm) received during quarter 4 of previous year or quarter 1 of this year	1.75	0.21	8.45
β_2	Q_2	76.4 ± 49.6	Amount of rainfall (mm) received during quarter 2	0.86	0.33	2.64
β_3	Q_3	161 ± 77.7	Amount of rainfall (mm) received during quarter 3	2.22	0.17	13.24
β_4	LNGUSA	1.8 ± 2.5	Natural log of broom snakeweed weight (kg/ha)	-33.96	5.73	-5.93
R^2				0.31		
n				383		
Mean ± Std of dependent variable (Grass Yield, kg/ha)				651 ± 355		
Root mean square error				295		

Note: All parameters were statistically significant at the 0.01 level or higher.

Source: Torell et al. (2007)



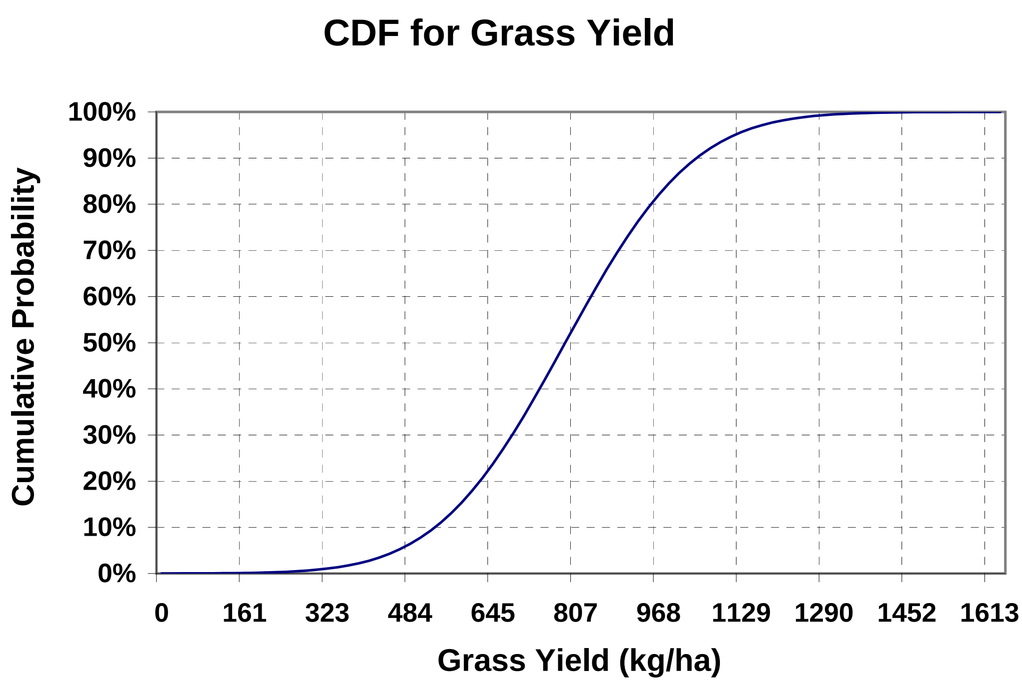


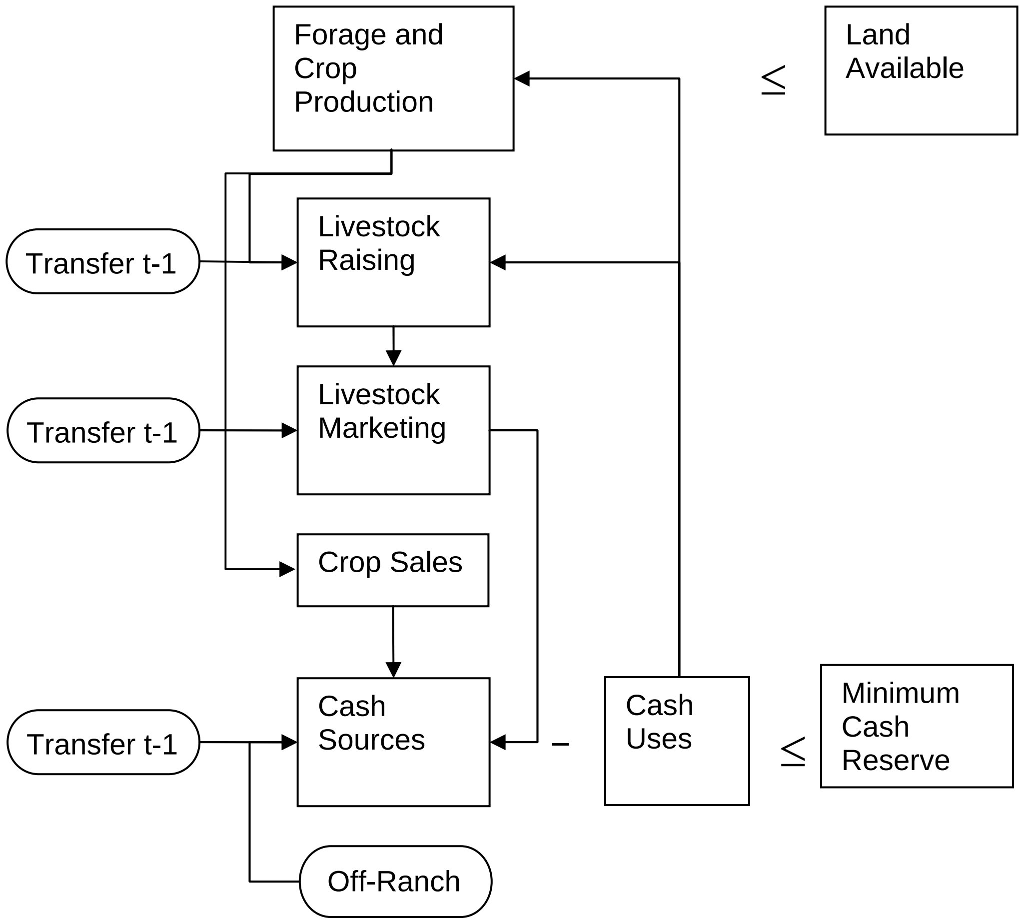
Figure 5. Probability Density Function (PDF) and Cumulative Density Functon (CDF)distributions for grass yields on the blue grama rangelands on the Corona Ranch.

THE MULTI-PERIOD LINEAR PROGRAMMING MODEL

The multi-period linear programming model adapted to the Corona Ranch was originally developed by the Western Regional Rangeland Economic Research Coordinating Committee W-192 to study public land policy issues (Torell et al. 2002). The model uses the Generic Algebraic Modeling System (GAMS) software (Brooke et al. 2005). The objective function in the linear programming problem is to maximize the net present value (NPV) of discounted net annual returns over a 40-year planning horizon subject to linear constraints that define resource limitations and resource transfers between years. Seasonal forage supply and demand is explicitly considered. The general structure of the LP model for a given year t is illustrated in Figure 6. The model equations are discussed from top to bottom in the figure.

The first block of constraints recognizes that a ranch has a limited amount of rangeland available for forage harvest. Seasonal use limitations can also be imposed to recognize that certain forages may be restricted in use to only selected seasons because of regulation, physical availability and production limitations. Harvesting rangeland forage allows the transfer of AUMs to cattle raising and forage leasing activities. If crops are raised, which they are not on the Corona Ranch, they are transferred as well.

The second block of equations defines forage transfer to livestock raising, forage leasing, and crop sale activities. Other equations defined in the livestock raising block define typical production rates like calf crop, sale weights, bull to cow ratios, etc. Seasonal forage requirements for each animal class is calculated based on



Source: Torell et al. (2002)

Figure 6. Linear Programming model constraint structure.

defined animal unit equivalencies and their presence on the ranch during a particular season and forage demands by season. Equations are also included that transfer breeding animals from year t-1 to year t. Animal death losses for different animal classes are considered at the time of transfer. The next block includes equations that relate animals raised to livestock selling activities.

The cash sources block defines the cash flow constraint which is another potential resource limitation in the model. Livestock sales, crop sales, and forage leasing are considered as sources of income from the ranch. Forage and livestock raising activities use cash. The included restrictions in the model recognize that each year, net returns from the ranch, off ranch income and accumulated wealth must be greater than or equal to calculated ranch expenses so as to cover variable production expense, fixed ranch expenses, family living expenses, loan obligations and an annual required cash residual. A frugal and profit maximizing enterprise is considered. It is assumed that some part of excess cash from a good year will be transferred to cover expenses and cash shortfalls in future years. Funds can be borrowed if a cash shortfall situation arises. Any funds borrowed must be repaid during the next year though repeat borrowing can occur for a number of years. In the model, borrowing is not allowed during the last year, and all loan obligations must be paid in full by the end of the 40-year planning horizon.

Corona Ranch LP Model

To develop the multi-period LP model for the Corona Ranch information from various planning documents for the ranch including a brush management plan (McDaniel et al. 2002), a base herd management plan (unpublished data provided by Mark Peterson, 2005), a financial analysis (SPA, Standardized Performance Analysis) conducted for the Corona Ranch and other New Mexico ranches (http://spatx.tamu.edu/), and a forage productivity and variability analysis performed from long-term field trials on the ranch (Torell et al. 2007) were considered. Input was also solicited from Shad Cox, Corona Ranch Manager, and Mark Peterson, Department of Animal and Range Sciences. Additional information for livestock enterprises not currently practiced on the ranch (purchasing yearling stockers, leasing forage, carrying over yearlings) was gathered from cost and return enterprise budgets prepared for Idaho (Marousek 2005, Smathers and Rimbey 2006) and New Mexico (http://costsandreturns.nmsu.edu, Graham 2007).

Assumptions about land area and productivity, animal production rates, and production costs and returns are described next along with detail about the restrictions included in the LP model. A printout of the GAMS model is included in Appendix A and the discussion below includes reference to the line number of the program listing where the restriction and/or related parameters are defined in the model. This program reference is included in square brackets [line reference]. An electronic copy of the GAMS model is available on the compact disk (Corona_LPmodel.gms). Similar to the model by Torell et al. (2002), optimal production and economic returns for the ranch was simulated over a 40-year planning horizon with 100 different iterations. Each iteration represents a different beef price situation.

Land Resources

The Corona ranch was originally fenced into large multiple section pastures, but currently the research center includes 53 pastures and traps of various sizes to accommodate better controlled grazing management as well as easier handling of various research projects. Pasture sizes range from a small 16 ha trap to several 130 ha unitized blocks, and several pastures that include 730 ha or more. These different pastures were grouped into 9 pasture units [168] based on similar location and the season of grazing use defined in the herd management plan (Figure 7, Table 2). Total

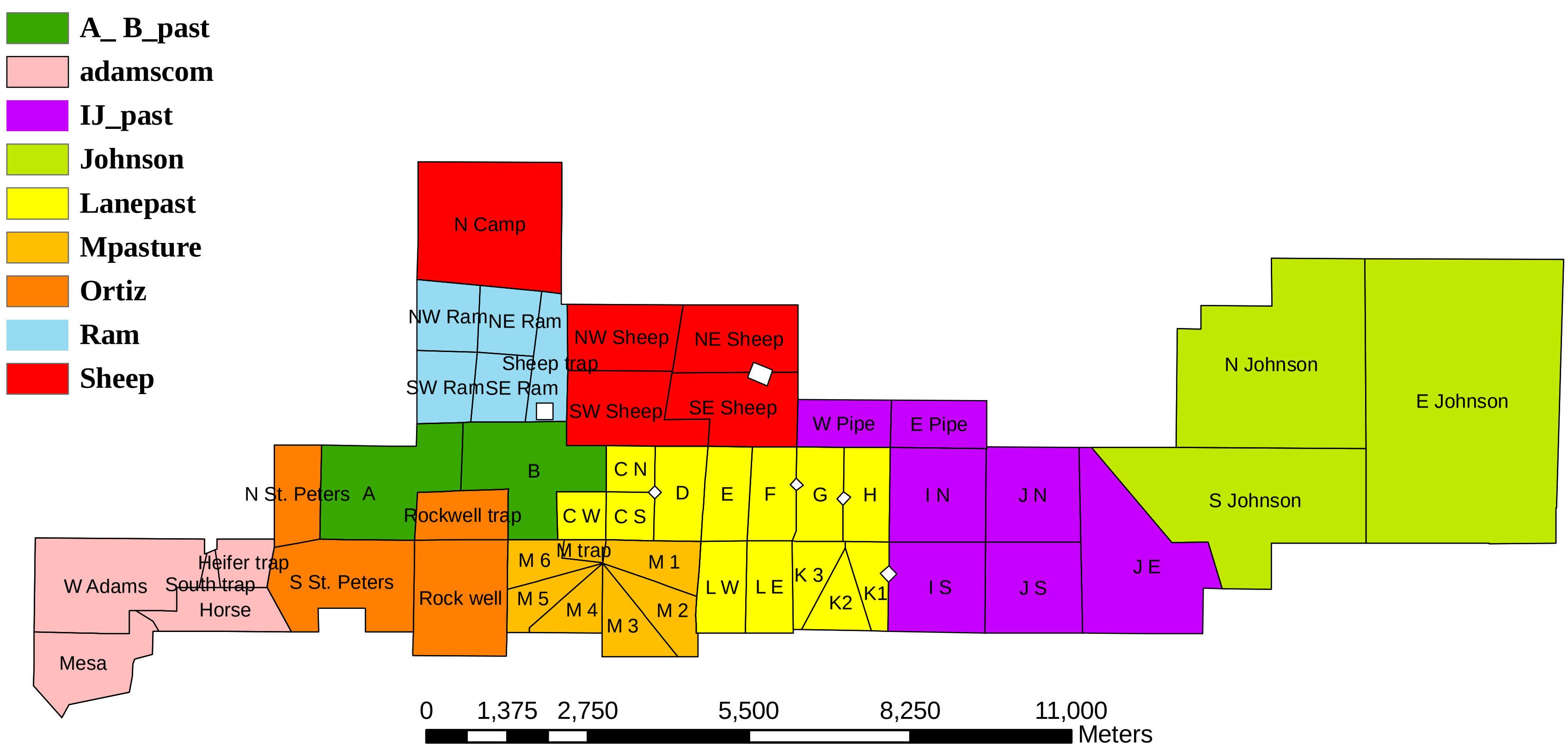


Figure 7. Location and classification of pasture units on the Corona Ranch.

Table 2. Defined resources and characteristics of the Corona Ranch.

	Units	Number of Units		Objective Function Cost ($/unit)
Land resources owned				
adamscom	Acres	2,107		$1.37
Johnson	Acres	7,937		$1.37
lanepast	Acres	3,299		$1.37
A_B_past	Acres	1,685		$1.37
Mpasture	Acres	1,430		$1.37
IJ_past	Acres	4,370		$1.37
Ortiz	Acres	2,254		$1.37
sheep	Acres	3,593		$1.37
ram	Acres	1,437		$1.37
Total	Acres	28,112		
Land resources leased or purchased				
Private leased forage	AUMs	6,000		$20.00
Purchase alfalfa hay	Tons	100		$200.00
Livestock resources				
Animal units yearling	AUY	268		
Brood cows	Head	194		58.50
Cull cows	Head	32		58.50
Steer yearlings	Head	0		117.00
Heifer yearlings	Head	7		117.00
Yearling replacement heifers	Head	74		58.50
Weaner replacement heifers	Head	33		Included with cow
Purchased steer calf	Head	0		82.00
Purchased heifer calf	Head	0		82.00
Bulls	Head	15		Included with cow
Horses	Head	7		Included with cow
Miscellaneous income/expenses				
Fixed ranch expenses	$			$43,921
Family living allowance	$			$0
Additional annual ranch income	$			$35,000
Initial wealth	$			$35,000
Required minimum cash reserve	$			$10,000
Efficiency and ratio measures				
Calf crop (Calves born as % of Jan. 1 cow inventory)	%	86		
Calf death loss	%	3		
Cow death loss	%	1		
Bull death loss	%	1		
Raised yearling death loss (including time as calf)	%	5		
Purchased yearling death loss	%	3		
Steer calf sale weight	lb	520		
Heifer calf sale weight	lb	480		
Ranch raised steer yearling sale weight	lb	810		
Ranch raised heifer yearling sale weight	lb	770		
Leased forage dates	Date	1-May	1-Oct	
Purchased yearling purchase and sale date	Date	1-May	1-Oct	
Purchased steer yearling purchase and sale weight	lb	400	660	
Purchased heifer yearling purchase and sale weight	lb	400	650	
Cull cow sale weight	lb	1,000		
Cull bull sale weight	lb	2,000		
Bull to cow ratio	Ratio	1:20		
Cow replacement rate	%	12		
Bull replacement rate	%	14		
Minimum yearling heifers for sale	%	10		
Productive life of cows	Years	10		
Productive life of bulls	Years	6		

ranch acreage is 28,112 acres (11,381 ha). It was assumed outside forage could be leased up to a maximum of 6,000 AUMs, which would be enough forage for the 345 AUY Corona Ranch cow herd for a year if forage shortages existed. Additionally, up to 100 tons of hay can be purchased at $200/ton ($0.045/kg), including delivery to the ranch [179]. Hay purchase is restricted using the crop production equation [328].

Forage can be harvested from pastures in any of 6 defined seasons (Table 3) [113, 142]. The seasons are defined based on typical dates when certain events occur on the ranch, like calving, weaning, shipping, grass green up, etc.

The first constraint in the model limits land acreage for each pasture type to be less than or equal to the acreages shown in Table 2 [326]. Land can remain unused, or in the terminology of linear programming, be allocated to a "slack variable".

Animal Classes and Ratios

The Corona Ranch has had a cow-calf enterprise and a sheep enterprise. The sheep enterprise was not included in this economic analysis because a historical series of sheep prices is not available. Livestock raising activities considered in the model include 1) the typically practiced cow-calf enterprise with sale of calves in the fall;

Table 3. Grazing seasons on the Corona Ranch.

Seasons	Grazing Period	Days
Season 1	1-March to 1-May	61
Season 2	1-May to 1-June	31
Season 3	1-June to 1-October	122
Season 4	1-Octerber to 1-November	31
Season 5	1-November to 1-December	30
Season 6	1-December to 1-March	90
Total		365

2) a cow-yearling enterprise where weaned calves are carried over and not sold until the following fall; 3) the purchase of yearlings whereby 400 lb (201 kg) calves are purchased May 1 and sold Oct. 1; 4) and forage leased to an outside yearling operator for seasons 2 and 3. The cow-calf and cow-yearling enterprises require other animal classes such as bulls, calves, cull cows and replacement heifers be produced at a fixed ratio, and a number of equations are included to define these ratios. Seven horses are maintained on the ranch yearlong for production activities. Animal classes defined in the model are shown in Table 4.

A cow transfer equation [364] limits the number of brood cows at time t to be less than or equal to the number of cows purchased at time t, plus the number of

Table 4. Animal class description.

Animal Class	Description
broodcow	Mature cow that will be maintained for another year
cullcow	Mature cow that will be sold as a cull animal at a weight of 1,000 lb (454 kg)
bull	Breeding bull that will be maintained for another year
horse	Horse
scalf	Steer calf that will be sold in the fall at a weight of 520 lbs (236 kg)
hcalf	Heifer calf that will be sold in the fall at a weight of 480 lbs (218 kg)
syear	Ranch raised steer calf carried over for sale the following fall at a weight of 810 lbs (367 kg)
hyear	Ranch raised heifer calf carried over for sale the following fall at a weight of 770 lbs (349 kg)
purscalf	Steer calf purchased at 400 lb (181 kg) and sold for 660 lbs (299 kg)
purhcalf	Heifer calf purchased at 400 lb (181 kg) and sold for 650 lbs (295 kg)
rephcalf	Heifer calf kept on the ranch as a replacement heifer
rephyear	Replacement heifer calf kept on the ranch for the second year
buybcow	Buy a brood cow to increase herd size
sellbcow	Sell a non-cull cow to reduce herd size
buybull	Buy a breeding bull

brood cows and replacement heifers transferred from year t-1. Similarly, bulls at time t must be transferred from the previous year or purchased [367]. Heifer calves kept as replacements at t-1 become yearling replacements at time t [369]. With each animal transfer a death loss is subtracted (Table 2).

Mature brood cows, cull cows, and replacement yearlings are bred over the year and the number of bulls raised must be a constant ratio to the total of these breeding females, as defined by the bull to cow ratio (Table 2) [371]. Part of the cow herd must be replaced each year. The culling rate is defined to be the ratio between the number of mature brood cows plus yearling replacement heifers, versus cull cows. This ratio (with adjustment for death loss) must be a fixed number depending on the defined cow replacement rate [373]. The minimum number of replacement heifers raised, or cows purchased, must be greater than or equal to the required replacement rate [376]. Retained replacements and cow purchases can exceed this ratio, implying a growth in the cow herd. Only 50 percent of the heifer calves are assumed to be suitable for replacements [379]. More yearling replacement heifers (10 percent) must be produced than will actually move into the cow herd and these excess animals will be sold as yearling heifers (*hyear*) [375].

Yearling replacements (*rephyear*) and mature cows (*broodcow*) produce calves. The assumed calving rate is 86 percent (Table 2). Half of the calves are steers and half are heifers. Steer calves can either be raised as calves (*scalf*) or carried over as yearlings (*syear*) [380, 382]. Heifer calves can be raised as calves (*hcalf*), yearlings (*hyear*) or replacements (*rephcalf*) [384, 386]. The assumed average rate of gain if carried over as yearlings is 0.8 lb/head/day (0.36 kg/head/day), suggesting average sale weight for yearlings would be 810 lbs (367 kg) for steers and 770 lbs (349 kg) for heifers [229].

The Corona Ranch currently has 194 brood cows. Thus, the model is given an initial endowment of 194 mature cows [432] and 74 yearling replacements [433]. From this first year, cow numbers can only increase by raising replacements or by purchasing cows, and the dynamic equation system described above regulates the potential growth rate.

Forage Balance

Each class of animal has forage requirements based on the animal unit equivalencies defined for each season and their presence on the ranch during a particular season. The number of months in a season is multiplied times the AU equivalency factor to compute AUMs required during a particular season. Two different AU equivalency tables are used in the calculation, one for animals maintained during year t [185] and one for yearling animals carried over to year t+1 [204]. Calves are born in March and April and sold October 1. A forage requirement is not considered for calves. Calves carried over for sale or herd replacement have a forage requirement beginning Oct 1 (Season 3). Cull cows are sold November 1 (beginning of season 5) and do not have forage demand during the winter. Replacement heifers have an increasing forage demand as they mature [217].

It is assumed that if forage leasing is optimal, outside yearlings will be on the ranch from May 1 to Oct. 1 (season 2 and season 3). Thus, if forage is leased, AUMs must be leased during both seasons 2 and 3 in a ratio equal to the relative length of the two seasons [354].

The activity of using or harvesting rangeland forage from the various pasture units described above provides forage to meet animal demands, or for forage lease. The AUMs provided per acre was considered to be variable by year and this varying annual amount of forage production is an addition to the original LP model structure developed by Torell et al. (2002). As noted earlier, without snakeweed present and using long term rainfall data it was estimated that average forage production on the Corona Ranch follows a normal distribution with a mean of 768 kg/ha and with a standard deviation of 200 kg/ha (Torell et al. 2007). Yet, as shown in Table 1, grass yields measured on study plots from 1990 through 2006, which had snakeweed present, averaged a lower amount, 651 kg/ha. In the modeling analysis, this more conservative estimate of average grass yield was considered. For a particular year t, an estimate of year-end mean forage production is drawn from a normal distribution with a mean of 651 kg/ha. The standard deviation of the mean is assumed to be 200 kg/ha [254]. The Bement (1969) stocking rule of leaving 336 kg/ha was followed and this residual amount of forage had to remain at the end of each growing season. With the imposed residual allowance, overgrazing or increasing grazing pressure beyond that which would give near maximum gains per ha was not allowed. Yet, as noted by Bement (1969) removing forage below this optimal level is another potential drought adjustment strategy, though reduced animal gains will result and potential rangeland productivity declines could result. It is common for New Mexico ranchers to reduce forage levels to below optional levels during periods of drought (Gray et al. 1983).

Once the required forage residual was subtracted, the model checks to assure that a positive amount of forage remains and then computes the harvestable amount of forage produced per acre [255]. This estimate of AUMs/acre is for the relatively productive blue grama rangeland areas on the ranch. Other pastures with pinyon-juniper invasion and shallow soils would not be as productive as the blue grama areas. An index of relative productivity for each of the 9 pasture units (Table 5) was determined based on historically observed forage productivity differences (Shad Cox, personal communication, May 22, 2007). The productivity index was multiplied times the estimated blue grama rangeland acres/AUM value to estimate the productivity of each pasture unit during a particular year. Based on the mean annual grass yield being normally distributed with a mean of 651 kg/ha, following the Bement (1969) stocking guide and assuming an 800 lb (363 kg) AUM, Table 5 also shows the average

Table 5. Relative productivity of Corona Ranch pastures units.

Pasture Units	Relative Productivity	Average Carrying Capacity (AUY/Section)
adamscom	1.00	18.7
Johnson	0.70	13.1
lanepast	0.94	17.6
A_B_past	0.77	14.4
Mpasture	0.52	9.7
IJ_past	0.74	13.8
Ortiz	0.85	15.9
sheep	1.00	18.7
ram	1.00	18.7
Average		**15.0**

Note: Pasture units are shown in Figure 7.

rangeland carrying capacity estimated for each pasture unit. With 44 sections on the Corona Ranch the average carrying capacity of the ranch is estimated to be about 660 AUY which is nearly twice the 345 AUY base herd size desired for the ranch (Unpublished data, Corona Ranch, Advisory Committee Meeting, 2006). There appears to be much potential to harvest additional AUMs during favorable production years if these productive years can be anticipated.

Three different forage transfer equations are included in the model. The first equation transfers forage for the first year which does not include a forage demand for yearlings (because they have not yet been raised) [331]. The second equation is for seasons 1 and 2 [339] which occur before annual grass growth substantially begins in June. Forage harvested during seasons 1 and 2 must be carried over from the previous year. An estimated 13 percent of the forage is assumed to be lost over the late dormant season from natural decay (Pieper et al. 1974). The third equation considers seasons 3 through 6 where forage is supplied from current year production. The AUM/acre coefficient estimated for year t for each pasture unit is multiplied times the computed optimal number of acres used for each pasture unit and added to any purchased hay or leased forage AUMs to define forage supply. Each ton of purchased hay is assumed to supply 2.42 AUMs [179]. The three equations specify that total AUMs used or demanded must be less than or equal to the total AUMs supplied.

For accounting purposes and so that the total ranch carrying capacity could be restricted to different level for alternative scenarios, the total cattle AUY demand, plus leased forage demand was computed [357, 361].

Livestock Sales

Livestock sales are calculated based on the sale weight of each animal class (Table 2) after subtracting an appropriate death loss. The sales transfer equation [390] recognizes that livestock sales for each animal class must be less than the sale weight for each animal class times the number raised, net of death loss.

Objective Function

The objective function for the LP problem is to maximize the net present value of discounted net annual returns (return over variable plus fixed expenses) over a 40-year planning horizon. A 7 percent discount rate was used [37, 403]. The ranch starts the production process in year 1 with an inventory of breeding animals. From this point, during years 2 through 40, the model is free to adjust herd size (purchase or sell) or select the alternative enterprises of leasing forage or raising yearling stockers. Variables in the model are set to profit-maximizing levels subject to forage, cash limitations, and profitability. The interdependence between years is explicitly recognized. Forage and pasture resources can be grazed or not grazed depending the potential contribution to profit.

Net returns are defined as gross returns minus forage harvest costs, animal raising costs, loan repayment costs, and fixed costs [402]. Gross returns are calculated as the number of animals optimally raised of various classes multiplied by the sale price for that animal class, plus the sum of leased forage multiplied times the lease price for forage [399]. In this model no crops are raised so crop selling activities are not included. Beef prices, costs, and forage lease rates used in the analysis are described in greater detail below.

Cash Flow Constraint

The cash flow constraints in the LP model require all variable costs, fixed costs, borrowing costs, and family living expenses to be covered each year, given calculated annual ranch returns and other assumptions about off-ranch income (Torell et al. 2002). A minimum cash reserve of $10,000 must be maintained each year [425]. Cash reserves are accumulated as a parameter called *Frugal* times Net Returns + Off Ranch Income – Family Living Allowance [401, 408]. *Frugal* was set at 50 percent with the assumption being that only half of excess annual net returns would be saved for use in the future. This proportion recognizes that some excess funds will be spent and the 50 percent level was chosen without strong justification. If a cash short-fall arises annual borrowing was allowed with a 9 percent annual interest rate [48, 408].

On the Corona Ranch, additional income from wildlife was about $58,000 in 2004. Wildlife income was slightly more than livestock income on the ranch that year (Torell and Rimbey 2005). Deer numbers have declined on the ranch and a sustainable level of wildlife income is considered to be about $35,000/year (Personal communication, Shad Cox, June 12, 2007). This amount was assumed as the initial wealth available in year 1 and as additional ranch income in years 2 through 40. Thus, the first source of cash used to meet any cash shortfalls from livestock enterprises was the wildlife income [44, 406].

Because all Corona Ranch employees are salaried employees, no family living allowance was included. Total fixed costs were assumed to be $43,921 as described in greater detail below. With the relatively high amount of wildlife income, assuming this income source subsidizes the livestock enterprises when necessary, the cash flow constraint was rarely binding. A sensitivity analysis was performed to evaluate how production strategies would change if the ranch did not have this additional source of wildlife income.

Production Costs

The SPA analysis for the Corona Ranch indicates that the 2006 cow-calf enterprise operating costs totaled $91,079 ($469.48/cow). Costs and production rates for the Corona Ranch were similar to other New Mexico ranches also considered in the SPA analysis. Cow-calf enterprise costs exclude expenses for research and sheep production. The Corona SPA analysis was the basis for production cost estimates used for the cow-calf enterprise.

Cow-Calf Enterprise Costs.

Labor cost defined in the Corona Ranch cow-calf SPA analysis ($35,868, $184.89/ cow) was the largest expense category, and for the Corona Ranch all of the labor is hired. Most commercial New Mexico ranches hire very little labor with the labor expense reflecting a residual return to the ranch owner and family labor input. Labor expense is likely also not linear with substantial economies of size for some activities like checking animals while on rangeland. Labor for research activities have already been subtracted from the SPA analysis expense category.

The problem is allocating labor expenses between livestock raising activities and other activities like ranch maintenance and upkeep that would not vary with the number of cows raised. Cow-calf enterprise budgets prepared for Idaho (Marousek 2005, Table 1.1) indicate livestock and forage harvesting activities take about 9 hours per cow for the year. At this level and valued at $12/hour, the 194 cows on the Corona Ranch would take about $21,000 (1,746 hours or $108/cow) in labor expense. Thus, $14,868 of the total Corona Ranch labor expense is considered as a fixed expense that would not change as size of the cow herd changes, or other animal classes are produced.

Depreciation and utility expenses included in the SPA analysis ($7,933) were also considered to be fixed costs, though an unknown part of the electricity expense was for pumping livestock water, a variable expense. Based on livestock enterprise budgets reviewed, an additional fixed allocation was included for building and improvement maintenance. General vehicle maintenance and replacement charges were included so that the total ranch maintenance expense was considered to be $20,000/year.

Another fixed expense was considered to be grazing fees. Because, Bureau of Land Management (BLM) and New Mexico state trust land (STATE) leases are long-term leases, the Corona Ranch does not have the option of not paying or using these leases. Thus, a grazing fee payment of $9,053 was also included as a fixed cost in the model. Total fixed expenses including fixed labor ($14,868), ranch maintenance ($20,000), and grazing fees ($9,053) were then estimated to be $43,921 [43].

Some costs are incurred because livestock reside on rangeland areas and these costs were designated as forage harvesting costs. These costs would be incurred regardless the type of livestock raised (e.g. cow-calf, yearlings). Brush control costs in SPA of $3,067 ($0.11/acre) were included as grazing cost. Torell et al. (1993) estimated that on average in 1992, New Mexico ranchers spend an average of $3.27/AUM maintaining range improvements and providing water to livestock. This would be $4.56/AUM in 2005 dollars, or $1.37/acre ($3.38/ha), assuming 15 AUY/section (Table 5). This per acre amount was included as a grazing cost [170]. As implied by linear programming methods this expense can be bypassed by not grazing selected acreages. Also note that with the assumed grazing cost of $1.37/acre the implied grazing cost per AUM varies with the realized level of rangeland productivity. If, as an example, forage production was at the assumed average 651 kg/ha level this would mean 0.35 AUMs of harvestable forage per acre (with a required 336 kg/ha residual) for a cost of $3.91/AUM. If forage production was only 400 kg/ha (0.07 AUM/acre) the implied cost would be $19.57/AUM. Total forage production and harvesting costs would be $38,513 if all 28,112 acres are utilized.

Animal raising and production costs are computed as the SPA reported total operating costs minus forage harvest costs minus SPA expenses classified as fixed ($91,079 - $38,513 - $31,854 = $20,712). In the LP model animal production costs are assumed to be linear and allocated over the 2006 inventory of mature cows, cull cows and replacement heifers (354 head). The animal cost is then $20,712/354 head = $58.50/head [223, 224]. Included in this per head cost is the expense of checking animals while on rangeland. It was assumed that while on rangeland cattle must be checked 3 times each week with a 4 hour trip and 60 travel miles for each trip (Personal communication, Shad Cox, May 22, 2007). Mileage was valued at the Internal Revenue Service (IRS) rate ($0.45/mile) and labor was valued at $12/hour.

Cow-Calf -Yearling Enterprise.

Enterprise budgets prepared by Marousek (2005, Table 2S-2) with updated prices indicates that each calf carried over for sale as a yearling the following fall will cost $117/head [229] for the carryover (Table 6). In addition, interest charges on the carryover are computed separately in the LP model. Interest is charged at 7.5 percent for the year on the calf weight that could have been sold the previous fall [394]. Interest is also charged on the $117/head animal expense for 6 months. Forage harvest costs are computed separately in the model. It was assumed the yearlings carried over would add 1.64 hours of labor expense in addition to the 9 hours required to raise the cow with calf.

Purchased Yearlings.

Enterprise budgets prepared by Smathers and Rimbey (2006) and stocker cattle guidelines prepared by Graham (2007), with updated prices, indicate yearling production costs total $82/head (Table 6), excluding animal purchase costs, interest costs and range forage costs which are computed separately in the LP model. The assumed linear per head cost includes 1.64 hours of labor and alfalfa purchased and fed before animals are turned out on rangeland. Purchased yearlings generally spend some time in dry lot while the herd is assembled. Interest is charged on the $82/head

Table 6. Production costs for alternative enterprices.

Carry over Yearling Costs

Cost item	Units	# units	$/unit	Cost	$/head
Alfalfa hay	ton	134	$200	$26,800	$80.00
Salt	lb	4,527	$0.06	$272	$0.81
Supplement	cwt	400	$10	$4,000	$11.94
Labor	hours	550	$12	$6,600	$19.70
Miscellaneous	head	335	$5	$1,675	$5.00
Total cost				$39,347	
Dollar per head assuming 335 head are carried over					$117.45

Source: Marousek (2005)

Purchased Yearling Costs

Alfalfa hay	ton	22	$200	$4,400	$22.00
Salt	lb	1,200	$0.07	$84	$0.42
Labor	hours	328	$12	$3,940	$19.70
Vet and medicine	head	200	$4	$725	$3.63
Marketing	head	200	$19	$3,760	$18.80
Hauling	head	200	$11	$2,160	$10.80
Miscellaneous	head	200	$7	$1,400	$7.00
Total cost				$16,469	
Dollar per head assuming 200 head are purchased					$82.35

Source: Smathers and Rimbey (2006)

Leased Forage Costs

Lease forage	AUM	$16
Animal care[a]	AUM	$2.41
Forage production costs[b]	AUM	$4.56
Net lease price	AUM	$9.03

[a]/Checking 400 animals

[b]/assumed to be $1.37/acre as described in the text. The $/AUM cost varies with the computed annual carrying capacity.

animal expense for 6 months and on the animal purchase cost [394]. The biggest cost for yearling stockers is the cost of buying the animal. This expense varied by year depending on the defined beef price situation.

Leased Forage.

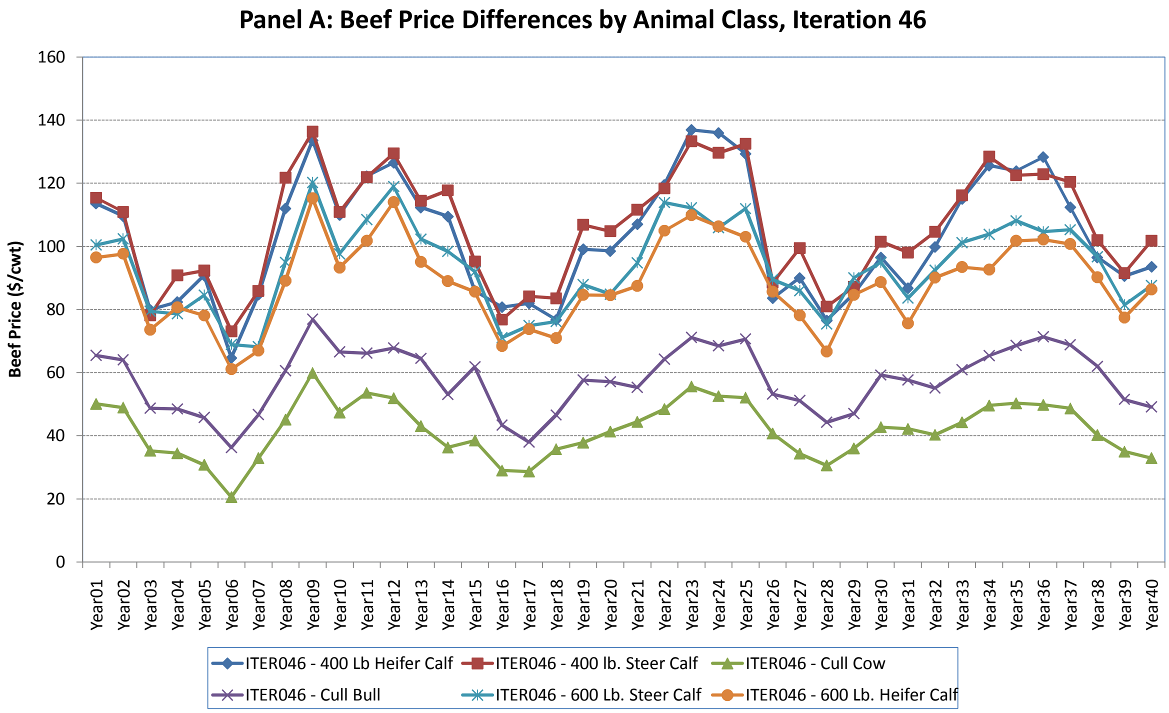
Instead of buying stocker animals another option considered is to lease forage to an outside yearling operator. The same grazing season is assumed as for owned yearlings; they would be on the ranch during season 2 and season 3. It was assumed that forage could be leased for $16/AUM (Table 6). This would be a full service lease whereby the Corona Ranch provides full care of animals. While on the ranch it was assumed yearlings would be checked 3 times each week with a 4 hour trip and 60 travel miles for each trip for a total cost of $225/week. Assuming 400 yearlings would be maintained this would be $2.41/AUM. Total costs would be about $7/AUM such that the net lease price would be about $9/AUM (Table 6). This would be similar to the net price obtained using a forage valuation technique described by Bartlett et al. (1993). As noted, studies in Idaho and New Mexico indicated that a reasonable estimate of net forage value (no services provided) was to multiply average private land lease rates reported by USDA-NASS (2007) by 70 percent. The 30 percent discount is for the value of services typically provided with the lease. NASS lease rates reported for the 11 western states in the last 3 years averaged $13.60/AUM. Using the 70 percent rule, average net forage value would be $9.52/AUM.

Input and Output Prices

Annual ranch income and optimal production strategies are greatly influenced by beef prices. To consider the effect of beef prices on ranch returns and optimal production strategies, a Monte Carlo analysis similar to that used by Torell et al. (2002) was considered. Different prices were generated for the different LP model iterations. Updated real livestock prices were stochastic exogenous variables in the LP model, and the model maximizes profit with knowledge about the 40-year history of prices. The price series generated by Torell et al. (2002) were updated to constant 2005 prices using the Consumer Price Index (CPI).

The beef price model was originally estimated using data for different weights of cattle supplied by Cattle-Fax, Inc™. It was determined that beef prices exhibit an approximate 12-year cycle. The model considers this cycle and the relative price spread between different livestock classes and the interdependence of beef prices for different animal classes at any point in time (Figure 8, Panel A). The 700 lb (283 kg) weight class was not included in the original price series so regression analysis was used to determine that the price for 700 lb (318 kg) steers is about 0.82 that of 400 lb (162 kg) steers. Similarly, the price for 700 lb. heifers was estimated to be 0.87 times the 400 lb weight. As noted by Torell et al. (2002), the price of young breeding bulls was also not reported in the Cattle-Fax data and it was determined that bulls sell for about twice that of bred cows [484]. This same relationship was assumed here.

Figure 8, Panel B shows 400 lb steer calf prices for 3 randomly selected iterations. The starting point for the series is random with 100 different iterations



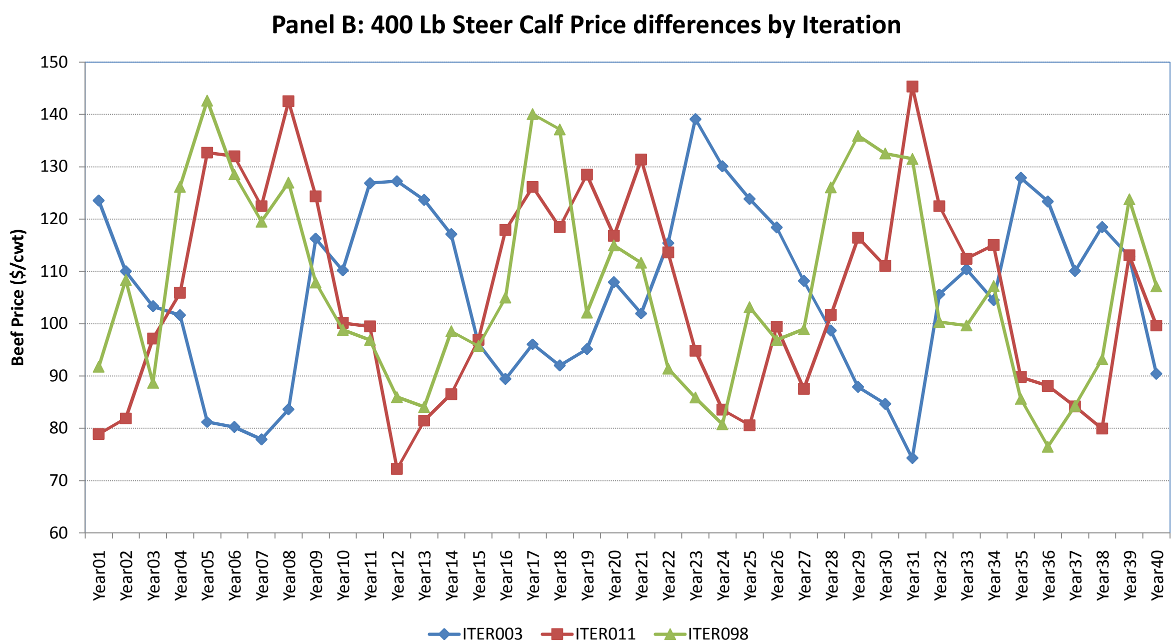


Figure 8. Beef Price Situation Comparisons For Selected Iterations.

considered. With 40 years in the planning horizon this means 4,000 different beef price situations were considered. Beef prices for each iteration are available on the compact disk in the spreadsheet called Beefprices.xls. Table 7 shows the overall average price by animal class. Annual averages include 100 price scenarios and are very near the overall averages reported.

Note that if forage conditions meant the cow herd size needed to be reduced by selling productive brood cows in addition to the normal culling rate, the price assumed for these sales was the cull cow price [482]. Thus, it was assumed that cow purchases are at the relative high bred-cow prices but cow sales occur at the discounted cull price.

As noted above, other prices considered in the model are the price for leasing outside forage to provide additional grazing capacity (assumed to be $20/AUM), the price for leasing Corona Ranch forage to an outside yearling operator ($16/AUM),

Table 7. Average beef price for different animal class.

Variable Name	**Description**	**Units**	**Average Price**	**Standard Deviation**
scalf	300-400 Lb. Steer Calf	$/cwt	$107	18
hcalf	300-400 Lb. Heifer Calf	$/cwt	$103	20
purscalf	600-700 Lb. Purchased Steer Calves[a]	$/cwt	$95	14
purhcalf	600-700 Lb. Purchased Heifer Calves[a]	$/cwt	$90	14
syear	700-800 Lb. Ranch Raised Steer yearling	$/cwt	$88	15
hyear	700-800 Lb. Ranch Raised Heifer Yearling	$/cwt	$89	18
cullcow	1,000 Lb. Cull Cow	$/cwt	$43	9
bull	3,300 Lb. Cull Bull	$/cwt	$58	11
buybcow	1,000 Lb. Buy Brood Cow	$/head	$925	195
buybull	1,000 Lb. Buy Bull	$/head	$2,054	401

[a]/ Calves are purchased at the 300-400 lb weight and sold at a 600-700 lb weight.

and the cost of purchasing hay ($200/ton). These prices were not varied by year. These output prices are considered when computing gross returns [399].

RESULTS

Alternative production and marketing strategies were evaluated for the Corona Ranch. The first scenario considers only a cow calf enterprise producing at no more than the desired bench mark level of 345 AUY (7.85 AUY/section) identified in the base herd management plan (Unpublished data, Peterson 2005). In all cases it was assumed that herd size is flexible downwards, providing the flexibility to either purchase additional leased forage or reduce herd size as potential adjustments to drought. The second scenario considers a 345 AUY maximum but expands to allow alternative production of purchased yearlings, carry over of calves as yearlings, and leasing of AUMs to outside yearling operators. Other scenarios consider an increasing maximum stocking rate for the ranch along with the scenario where the ranch manager could accurately project annual forage production and adjust stocking rates to use all available forage each year. This scenario demonstrates potential economic returns if an accurate weather or forage forecast were available.

Cow-calf Enterprise with 345 AUY Maximum

Table 8 presents the average and standard deviation (in brackets) of resources used, livestock production levels, and economic variables estimated to be optimal (profit maximizing) for the Corona Ranch when setting the desired base herd target (345 AUY) as a maximum and when managed as a cow/calf ranch only. With the specified production ratios (e.g. calf crop, replacement rates, bull to cow ratios, etc.) the average profit-maximizing herd would have 341 AUY, 240 cows, 33 cull cows, 37 replacement heifers, 16 bulls, 120 steer calves and 79 heifer calves. There was

Table 8. Optimal resource use and production strategies for cow/calf enterprise with 345 AUY maximum.

Panel A. Resource Use

Pasture Units	Units	Available Resources	Average Used	Average Slack	Average aumac	Average AUMs used
A_B_past	Acres	1,685	585 (86)	1100	0.28	101 (18)
adamscom	Acres	2,107	1874 (78)	233	0.36	734 (56)
IJ_Past	Acres	4,370	1134 (176)	3236	0.27	167 (27)
Johnson	Acres	7,937	1173 (289)	6764	0.25	137 (32)
lanepast	Acres	3,299	2068 (166)	1231	0.34	588 (62)
Mpasture	Acres	1,430	98 (33)	1332	0.19	8 (3)
Ortiz	Acres	2,254	991 (129)	1263	0.31	209 (33)
ram	Acres	1,437	1267 (51)	170	0.36	492 (38)
sheep	Acres	3,593	3165 (116)	428	0.36	1222 (88)
Total	**Acres**	**28,112**	**12,355**	**15,756**	**0.30**	**3,662**
Leased	AUMs	6,000	553 (138)	5447	1.00	553 (138)
purchalf	tons	100	0 (0)	100	0.00	0 (0)

Number in the parenthesis is the standard deviation measured over the 100 iterations and 40 years

Panel B. Animals Raised

Animal Class	Units	Numbers	
Maximum stocking rate allowed	AUY	345	
Average number of total AUY	AUY	341	
Average brood cows	head	240	
Average cull cows	head	33	
Average bulls	head	16	
Average steer calves	head	120	
Average heifer calves	head	79	
Average ranch raised steer yearlings	head	0	
Average ranch raised heifer yearlings	head	5	
Average replacement heifer calves	head	37	
Average replacement heifer yearlings	head	37	
Percent of years yearlings were purchased	%	0	
Average number of yearlings purchased	head	0	(when purchased)
Percent of years forage was leased to an outside yearling operator	%	0	
Average number of AUMs leased	AUM	0	(when leased out)
Percent of years forage was leased	%	21%	
Average amount of forage leased	AUM	2,618	(when leased)

Table 8. Continued

Panel C. Costs and Returns			
	Units	**Value**	
Gross Livestock Sales	$	122,679	
Average annual forage costs	$	27,977	
Average annual animal costs	$	24,549	
Average annual production cost	$	52,572	
Fixed Costs	$	43,921	
Average annual net returns	$	26,186	
Average annual net returns	$/AUY	77	
Maximum annual net returns	$	129,329	
Minimum annual net returns	$	-80,576	
Standard deviation of annual net returns	$	34,106	
Probability of negative annual net returns	%	20%	
Average annual accumulated savings	$	123,615	
Percent of iterations with borrowing	%	0.45%	
Average amount borrowed annually	$	9,429	(when borrowing occurred)
Average objective function value	$	326,015	
Maximum objective function value	$	475,287	
Minimum objective function value	$	98,675	
Standard deviation of objective function	$	73,004	

Run summary file: Cow calf -345 AUY-Maximum.xls minimal variation from this level for alternative years and price situations. Herd size was assumed to start at the current 194 brood cows (267 AUY when all animal classes are considered). By the second year herd size would increase to the target 345 AUY and generally remain there over the 40 year planning horizon. After year 1, herd size was at the target 345 AUY 80 percent of the time.

With management as a cow/calf ranch, the major way that drought years were managed was to lease outside forage to meet any forage shortages, assumed to cost $20/AUM. Some amount of forage was leased in 844 of the 4,000 iterations (21 percent of the time). As noted earlier, forage production was assumed to be normally distributed with a mean of 651 kg/ha and a standard deviation of 200 kg/ha. A forage residual of 336 kg/ha was required, implying no grazing capacity when forage production was below this level. Computed as the area under the normal curve no grazing capacity would be expected on the ranch about 6 percent of the time. The maximum number of AUMs leased in these low production years would be about 4,200 AUMs. Herd size was reduced slightly in some years but it was above 330 AUY 95 percent of the time. Herd reduction would be used to adjust to forage shortages only when forage shortages occurred late in the 40 year planning horizon. At $20/AUM it was more profitable to lease forage than to cut the size of the cow herd, given cow/calf production is the only production option considered.

The cow herd was maintained by raising replacement heifers on the ranch. In only 15 of 4,000 price situations (<0.5 percent) were cows purchased in addition to raising replacements. These were years when cows were relatively cheap (<$500/head in some cases).

Panel A in Table 8 shows that on average 15,756 acres or 56 percent of the available land resources would optimally go unused. This is because with the assumed level of average forage production on the ranch (estimated to be 15 AUY/section) the 345 AUY base herd (7.85 AUY/section) is a very conservative stocking rate (there is excess forage in many years). The least productive pastures would go unused first.

Panel C in Table 8 shows estimated average economic variables for the current cow/calf enterprise. Average annual net returns (return to land, management and risk) were estimated to be $26,186 ($77/AUY, $109/brood cow) with a great deal of variability (standard deviation of $34,106). By comparison, the 2006 SPA analysis for the Corona Ranch indicated an average net income from the cow/calf enterprise of $109/cow and the 2005 analysis shows $202/cow. These values are not directly comparable, however, because of definitional differences and the value computed here is averaged over 4000 alternative beef price situations whereas the SPA analysis is for a particular year.

Negative annual returns occurred in low beef price years and when forage production was low. Expensive leased forage was required to meet forage shortfalls in these years. About 20 percent of the iterations had negative annual returns from livestock production, requiring a subsidy from the wildlife enterprise. Additional borrowing was required about 0.45 percent of the time. The average objective function value (discounted net returns over the 40-year planning period) was $326,015.

Multiple Enterprises with 345 AUY Maximum

Maintaining the restriction of 345 AUY maximum but with the additional enterprises of carrying over yearlings, purchasing yearlings, and leasing forage to an outside yearling operator is now considered in addition to a cow/calf enterprise. The LP model results for this scenario are presented in Table 9. Average net annual returns are not greatly different considering the added enterprises, increasing only $648/year to $26,834 ($79/AUY). The value of the objective function was increased by $31,571, from $326,015 to $357,587. Carrying over calves for sale as yearlings was not as profitable as selling calves in the fall at the assumed production rates and costs, thus, carrying over yearlings beyond what was required to replace the herd was never practiced.

The cow herd would be maintained, though at a slightly lower level (194 brood cow average instead of 240 head average with only cow/calf operation). Approximately 10 percent of the time no cows would be raised. Instead, available forage would go to purchased yearlings or in other years forage would be leased to an outside yearling operator. In the early years of the planning period both cow/calf and yearlings enterprises would be profitable with yearlings purchased in selected years and maintained on the ranch along with the cow herd. As shown in Figure 9, which plots average brood cow numbers and AUY equivalents of yearlings, by year (averaged over by 100 price iterations), a complete switch to a yearling enterprise

Table 9. Optimal resource use and production strategies for multiple enterprise with 345 AUY maximum.

Panel A. Resource Use

Pasture Units	Units	Available Resources	Average Used	Average Slack	Average aumac	Average AUMs Used
A_B_past	Acres	1685	588 (93)	1097	0.28	102 (18)
adamscom	Acres	2107	1871 (71)	236	0.36	734 (53)
IJ_Past	Acres	4370	1137 (199)	3233	0.27	168 (30)
Johnson	Acres	7937	1190 (336)	6747	0.25	140 (38)
lanepast	Acres	3299	2077 (159)	1222	0.34	592 (52)
Mpasture	Acres	1430	96 (41)	1334	0.19	8 (4)
Ortiz	Acres	2254	998 (131)	1256	0.31	212 (32)
ram	Acres	1437	1266 (52)	171	0.36	493 (36)
sheep	Acres	3593	3176 (111)	417	0.36	1229 (77)
Total	Acres	**28,112**	**12,399**	**15,711**	**0.30**	**3,678**
Leased	AUMs	6000	520 (141)	5480	1.00	520 (141)
purchalf	tons	100	0 (0)	100	0.00	0 (0)

Number in the parenthesis is the standard deviation measured over the 100 iterations and 40 years

Panel B. Animals Raised

Animal Class	Units	Numbers	
Maximum stocking rate	AUY	345	
Average number of total AUY	AUY	340	
Average brood cows	head	194	
Average cull cows	head	27	
Average bulls	head	13	
Average steer calves	head	97	
Average heifer calves	head	65	
Average ranch raised steer yearlings	head	0	
Average ranch raised heifer yearlings	head	3	
Average replacement heifer calves	head	29	
Average replacement heifer yearlings	head	30	
Percent of years yearlings were purchased	%	59%	
Average number of yearlings purchased	head	279	(when purchased)
Percent of years forage was leased to an outside yearling operator	%	19%	
Average number of AUMs leased	AUM	948	(when leased out)
Percent of years forage was leased	%	20%	
Average amount of forage leased	AUM	2,556	(when leased)

Table 9. Continued.

Panel C. Costs and Returns

	Units	Value	
Gross Livestock Sales		204,021	
Average annual forage costs	$	27,814	
Average annual animal costs	$	105,430	
Average total production costs	$	133,265	
Fixed Costs	$	43,921	
Average annual net return	$	26,834	
Average annual net return	$/AUY	79	
Maximum annual net returns	$	154,213	
Minimum annual net returns	$	-84,749	
Standard deviation of annual net returns	$	35,874	
Probability of negative annual net return	%	20.75%	
Average annual accumulated savings	$	125,636	
Percent of iterations with borrowing	%	0.23%	
Average amount borrowed annually	$	8,849	(when borrowing occurred)
Average objective function value	$	357,587	
Maximum objective function	$	517,490	
Minimum objective function	$	147,675	
Standard deviation of objective function	$	72,977	

Run summary file: Multiple Enterprises-345 AUY-Maximum.xls

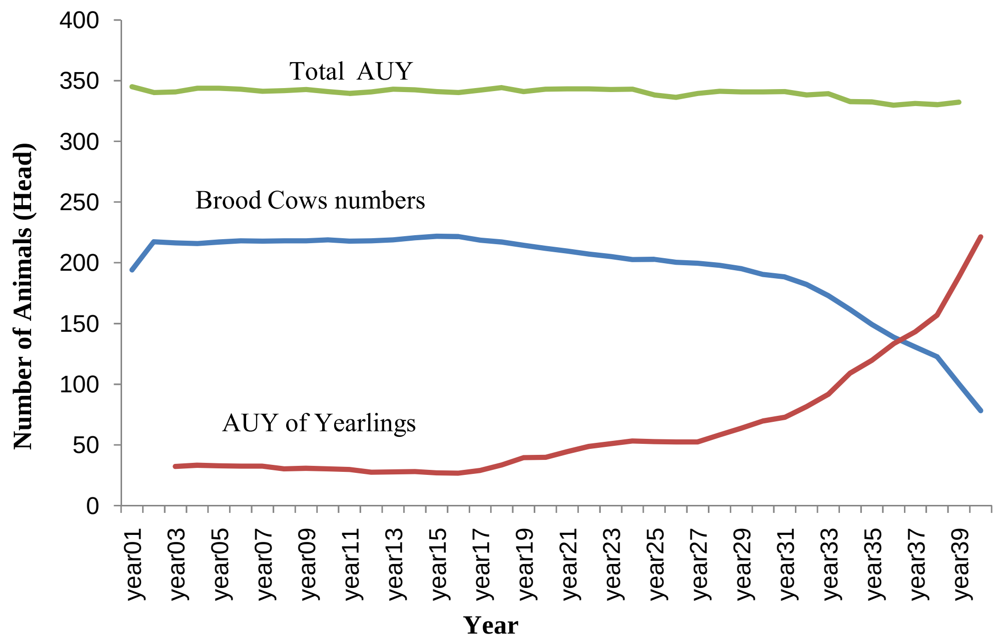


Figure 9. Average number of mature brood cows and AUY equivalents of purchased yearlings, or leased AUY, by year, in multiple enterprises with 345 AUY maximum.

generally occurred late in the planning horizon (after year 30). An evaluation of beef price situations during the year of the switch is consistent with expectations. The profitability of purchasing yearlings decreases as the price spread or difference between the buy and sell price increases. This is because part of the cost of yearling production is the loss of value on the original purchase weight as prices diminish at heavier sale weights (Figure 8). The switch to a yearling stocker operation occurred in a year when the price spread was negligible and it was never profitable to switch back to brood cows in the same 40-year planning period. The timing of the switch to yearlings was different for each price situation. Yearlings were purchased in 59 percent of the years and 87 percent of the time steer calves would be purchased. For those years when yearlings were purchased the average number purchased was 279 head (81 AUY).

In some years it was more profitable to lease forage to an outside yearling operator then it was to raise purchased yearlings. Leasing of forage to someone else occurred when the price spread for purchasing yearlings was wide. When forage was leased to an outside user an average of 948 AUMs was leased.

With more flexible enterprise opportunities, after year 1, herd size was at the target 345 AUY 90 percent of the time and above 300 AUY 95 percent of the time. Some amount of forage was leased in 814 of the 4,000 iterations (20 percent of the time) to meet forage shortfalls. When forage was leased an average of 2,556 AUMs were leased.

Multiple Enterprises with 660 AUY Maximum

The average grazing capacity of the Corona Ranch was estimated to be 15 AUY/section or 660 total AUY (Table 5). If maximum rangeland stocking rates were increased up to this level annual net returns would nearly triple, from $26,834 with only 345 AUY to $70,948 (Table 10). This assumes herd size is flexible downwards and would be adjusted downwards (or outside forage would be leased) to meet any forage shortfalls. These shortfalls occurred at an increasing frequency at the higher maximum stocking rate.

About 28 percent of defined land resources would optimally go unused with the 660 AUY maximum as compared to a level nearly twice this amount with only 345 AUY. The ranch would lease some amount of outside forage in about 37 percent

Table 10. Optimal resource use and production strategies for multiple enterprises with 660 AUY maximum.

Panel A. Resource Use

Pasture Units	Units	Available Resources	Average Used	Average Slack	Average aumac	Average AUMs used
A_B_past	Acres	1,685	1326 (84)	359	0.28	358 (30)
adamscom	Acres	2,107	1932 (60)	175	0.36	761 (50)
IJ_Past	Acres	4,370	2961 (217)	1,409	0.27	699 (59)
Johnson	Acres	7,937	3899 (437)	4,038	0.25	734 (90)
lanepast	Acres	3,299	2982 (105)	317	0.34	1092 (74)
Mpasture	Acres	1,430	490 (80)	940	0.19	64 (12)
Ortiz	Acres	2,254	1915 (90)	339	0.31	602 (44)
ram	Acres	1,437	1320 (40)	117	0.36	519 (34)
sheep	Acres	3,593	3297 (100)	296	0.36	1298 (86)
Total		**28,112**	**20,122**	**7,990**	**0.30**	**6,127**
Leased	AUMs	6,000	1216 (253)	4,784	1.00	1216 (253)
purchalf	tons	100	0 (0)	100	0.00	0 (0)

Number in the parenthesis is the standard deviation measured over the 100 iterations and 40 years

Panel B. Animals Raised

Animal Class	Units	Value	
Maximum stocking rate	AUY	660	
Average number of total AUYs	AUY	595	
Average brood cows	head	251	
Average cull cows	head	35	
Average bulls	head	16	
Average steer calves	head	127	
Average Heifer calves	head	81	
Average ranch raised steer yearlings	head	0	
Average ranch raised heifer yearlings	head	4	
Average replacement heifer calves	head	41	
Average replacement heifer yearlings	head	41	
Percent of years yearlings were purchased	%	61%	
Average number of yearlings purchased	head	1,007	(when purchased)
Percent of years forage was leased to an outside yearling operator	%	22%	
Average number of AUMs leased out	AUM	2,964	(when leased out)
Percent of years forage was leased	%	37%	
Average amount of forage leased	AUM	3,266	(when leased)

Table 10. Continued.

Panel C. Costs and Returns			
	Units	Value	
Gross livestock sales	$	$525,384	
Average annual forage costs	$	$53,458	
average annual animal costs	$	$357,046	
Average annual production costs	$	$410,515	
Fixed costs		43,921	
Average annual net returns	$	$70,948	
Average annual net returns	$/AUY	119	
Maximum annual net returns	$	$337,034	
Minimum annual net returns	$	-$107,967	
Standard deviation of annual net returns	$	$68,857	
Probability of negative annual net returns	%	16%	
Average annual accumulated savings	$	$213,731	
Percent of iterations with borrowing	%	0.10%	
Average amount borrowed annually	$	10,122	(when borrowing occurred)
Average objective function value	$	898,349	
Maximum objective function	$	1,263,556	
Minimum objective function	$	608,795	
Standard deviation of objective function	$	143,257	

Run summary file: Multiple Enterprises-660 AUY-Maximum.xls of the years and would lease the 6,000 AUM maximum allowed about 8 percent of the time. An average of 3,266 AUMs (272 AUY) would be leased when forage was leased.

Panel B in Table 10 shows average optimum livestock production estimated for various animal classes for the planning period with a 660 AUY maximum. The model ranch optimally maintained an average of 595 AUY. The cow herd size was maintained near the current level, averaging 251 head, but similar to the earlier results of Figure 9, average cow herd size decreased during the later years of the analysis because the opportunity cost (future earnings) of maintaining the cow herd diminishes each year. This was not always the case however. Cow numbers increased over the whole 40 years for 6 of the price iterations, peaking at about 500 head in these cases.

Production strategies were similar to the analysis with multiple enterprises operating at 345 AUY. Any additional grazing capacity was generally used by a more flexible yearling enterprise. The ranch purchased yearlings about 61 percent of the time. As earlier, in some years, it was more advantageous to lease forage to an outside yearling operator. When yearlings were purchased an average of 1,007 head (293 AUY) were bought for the 5 month grazing season.

Panel C in Table 10 shows averages estimated economic variables with 660 AUY, or when stocking rate is set at a maximum of 15 head/section. The annual net return was estimated to be $70,948 with a great deal of variability (standard deviation of $68,857). Average annual net returns are estimated to be $119/AUY. About 16 percent of the time annual net returns would be negative, requiring a subsidy from the wildlife enterprise. Additional borrowing was required about 0.10 percent of the time with the average amount borrowed at $10,122. The average objective function value was $898,349.

Cow-calf Enterprise with 660 AUY Maximum

Table 11 presents the average and standard deviation of resources used, livestock production levels, and economic variables estimated to be optimal if the 15 AUY/section average stocking rate were set as a maximum but only a cow/calf enterprise were considered. The annual net return was estimated to be $64,452 for the cow/calf enterprise, a decrease of $6,496 when compared to multiple enterprises (Table 10). Increasing the maximum herd size from 7.85 AUY/section to 15 AUY/section would increase annual average net returns by nearly 2.5 times when operated as a cow/calf ranch.

Production strategies were similar to the analysis of a cow/calf enterprise operating at 345 AUY. An average of 410 brood cows would be maintained on the ranch. About 25 percent of the time available land resources would not be fully used. The ranch would lease some amount of forage from outside about 42 percent of the years at an average of 3,362 AUMs. It would lease maximum allowed 6,000 AUMs about 9 percent of the time.

Table 11. Optimal resource use and production strategies for cow-calf enterprise with 660 AUY maximum.

Panel A. Resource Use

Pasture Units	Units	Available Resources	Average Used	Average Slack	Average aumac	Average AUMs used
A_B_past	Acres	1,685	1279 (136)	406	0.28	332 (52)
adamscom	Acres	2,107	1953 (68)	154	0.36	760 (54)
IJ_Past	Acres	4,370	2831 (342)	1539	0.27	641 (107)
Johnson	Acres	7,937	3645 (600)	4292	0.25	652 (134)
lanepast	Acres	3,299	2963 (180)	336	0.34	1058 (119)
Mpasture	Acres	1,430	457 (102)	973	0.19	56 (15)
Ortiz	Acres	2,254	1878 (171)	376	0.31	572 (79)
ram	Acres	1,437	1334 (45)	103	0.36	519 (35)
sheep	Acres	3,593	3332 (114)	261	0.36	1297 (90)
Total	**Acres**	**28,112**	**19,672**	**8,440**	**0.30**	**5,887**
Leased	AUMs	6,000	1385 (308)	4615	1.00	1385 (308)
purchalf	tons	100	5 (4)	95	0.00	0 (0)

Number in the parenthesis is the standard deviation measured over the 100 iterations and 40 years

Panel B. Animals Raised

Animal Class	Units	Numbers	
Maximum stocking rate allowed	AUY	660	
Average number of total AUY	AUY	588	
Average brood cows	head	410	
Average cull cows	head	57	
Average bulls	head	27	
Average steer calves	head	206	
Average heifer calves	head	127	
Average ranch raised steer yearlings	head	0	
Average ranch raised heifer yearlings	head	11	
Average replacement heifer calves	head	68	
Average replacement heifer yearlings	head	68	
Percent of years yearlings were purchased	%	0	
Average number of yearlings purchased	head	0	(when purchased)
Percent of years forage was leased to an outside yearling operator	%	0	
Average number of AUMs leased	AUM	0	(when leased out)
Percent of years forage was leased	%	42%	
Average amount of forage leased	AUM	3,262	(when leased)

Table 11. Continued

Panel C. Costs and Returns			
	Units	**Value**	
Gross Livestock Sales	$	$210,162	
Average annual forage costs	$	$55,718	
Average annual animal costs	$	$45,983	
Average annual production cost	$	$101,789	
Fixed Costs	$	43,921	
Average annual net returns	$	$64,452	
Average annual net returns	$/AUY	110	
Maximum annual net returns	$	$290,171	
Minimum annual net returns	$	-$108,217	
Standard deviation of annual net returns	$	$71,188	
Probability of negative annual net returns	%	20%	
Average annual accumulated savings	$	$199,152	
Percent of iterations with borrowing	%	0.63%	
Average amount borrowed annually	$	12,888	(when borrowing occurred)
Average objective function value	$	668,273	
Maximum objective function value	$	962,269	
Minimum objective function	$	257,545	
Standard deviation of objective function	$	135,673	

Run summary file: Cow-calf 660 AUY maximum.xls

Multiple Enterprises with Optimal Number of AUY

The ranch model was executed without any restrictions on maximum carrying capacity. Each year the ranch manager was assumed to know the level of forage production that would eventually be realized, and herd size would be adjusted to profit maximizing levels given this knowledge. This is obviously an unrealistic scenario that could only be achieved with a very accurate weather and forage forecast. It demonstrates the upper range of economic potential and highlights a general strategy that would be followed even without perfect foresight about prices and forage production levels.

Similar to runs with a restricted maximum herd size (Figure 9) the size of the cow herd would be consistently maintained at 150 to 230 head, averaging 189 head which is very near the current number. Similar to the earlier situation and description, the average number of cows would gradually decrease overtime, switching instead to the more flexible yearling enterprise as desirable price situations arose for yearling production. As shown in Figure 10, only about one-third of available AUMs would be harvested by the cow herd that must be maintained across years. Total AUY harvested on the ranch and from outside leased sources would average 890 AUY (Table 12). Average forage harvested on the Corona Ranch (excluding leased forage) would be 8,224 AUMs or 685 AUY, which is 15 AUY/section. This is as expected given that this was the assumed average grazing capacity of the Corona Ranch (Table 5). Outside forage would be leased in 56 percent of the years and this forage would be leased in many years, not only as forage for the cow herd during drought,

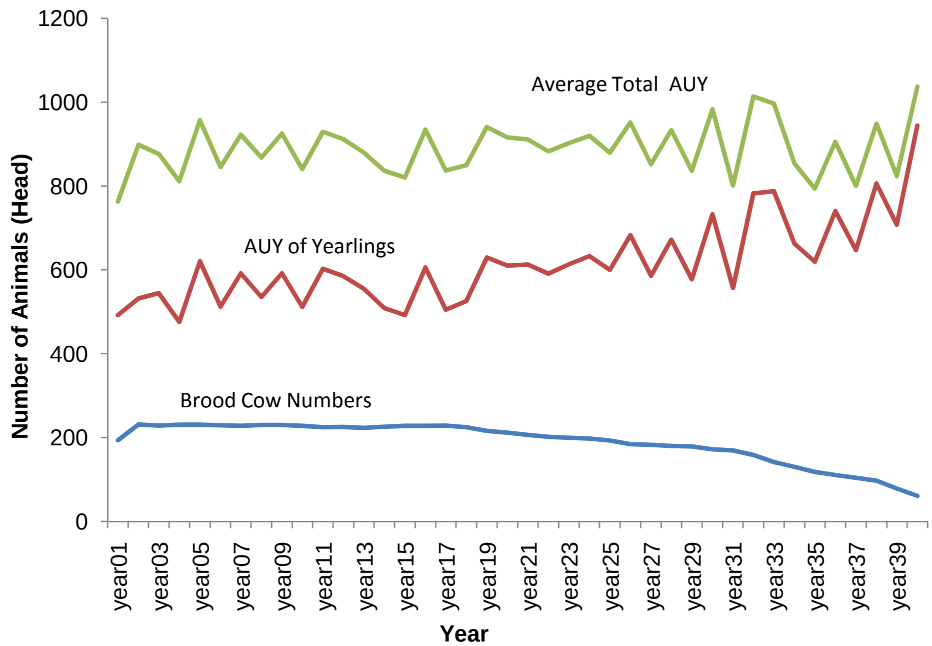


Figure 10. Average number of mature cows and AUY equivalents of purchased yearlings, or leased AUY, by year, in multiple enterprises with optimal stocking rates.

but also for yearling production during favorable price years. The ranch would lease the 6,000 AUM maximum allowed about 39 percent of the time. When forage was leased an average 4,959 AUMs (413 AUY) were leased.

With perfect foresight about forage production levels every blade of grass up to the required residual amount would be harvested. The ranch would fully utilize forage resources and take full advantage of favorable production years. It would do this primarily with a flexible yearling enterprise. Ranch produced forage would be inadequate to support the cow herd in about 21 percent of the years, additional forage would be available for yearling purchase (either owned or leased to an outside

Table 12. Optimal resource use and production strategies for multiple enterprises with optimal number of AUY.

Panel A. Resource Use

Pasture Units	Units	Available Resources	Average Used	Average Slack	Average aumac	Average AUMs Used
A_B_past	Acres	1,685	1512 (50)	173	0.28	465 (31)
adamscom	Acres	2,107	1931 (60)	176	0.36	761 (50)
IJ_Past	Acres	4,370	3900 (130)	470	0.27	1155 (77)
Johnson	Acres	7,937	6969 (238)	968	0.25	1966 (128)
lanepast	Acres	3,299	3008 (89)	291	0.34	1118 (73)
Mpasture	Acres	1,430	1175 (58)	255	0.19	253 (18)
Ortiz	Acres	2,254	2042 (64)	212	0.31	689 (45)
ram	Acres	1,437	1317 (41)	120	0.36	519 (34)
sheep	Acres	3,593	3295 (103)	298	0.36	1298 (85)
Total	**Acres**	**28,112**	**25,149**	**2,964**	**0.30**	**8,224**
Leased	AUMs	6,000	2752 (264)	3248	1.00	2752 (264)
purchalf	tons	100	0 (1)	100	0.00	0 (0)

Number in the parenthesis is the standard deviation measured over the 100 iterations and 40 years

Panel B. Animals Raised

Animal Class	Units	Numbers	
Maximum stocking rate	AUY	Not limited	
Average number of total AUY	AUY	890	
Average Brood cows	head	189	
Average cull cows	head	26	
Average bulls	head	12	
Average steer calves	head	95	
Average Heifer calves	head	63	
Average ranch raised steer yearlings	head	0	
Average ranch raised heifer yearlings	head	3	
Average replacement heifer calves	head	30	
Average replacement heifer yearlings	head	30	
Percent of years yearlings were purchased	%	58%	
Average number of yearlings purchased	head	2,916	(When purchased)
Percent of years forage was leased to an outside yearling operator	%	21%	
Average number of AUMs leased out	AUM	6,888	(when leased out)
Percent of years forage was leased	%	56%	
Average amount of forage leased	AUM	4,959	(When leased)

Table 12. Continued

Panel C. Costs and Return			
Items	**Units**	**Value**	
Gross livestock sales	**$**	1,193,397	
Average annual forage costs	$	93,024	
Average annual animal costs	$	940,350	
Average annual production costs	$	1,033,436	
Fixed costs	$	43,921	
Average annual net returns	$	116,040	
Average annual net returns	$/AUY	130	
Maximum annual net returns	$	1,326,918	
Minimum annual net returns	$	-176,972	
Standard deviation of annual net returns	$	158,869	
Probability of negative annual net returns	%	23%	
Average annual accumulated savings	$	304,116	
Percent of iterations with borrowing	%	0.40%	
Average amount borrowed annually	$	14,282	(when borrowing occurred)
Average objective function value	$	1,487,377	
Maximum objective function	$	2,627,048	
Minimum objective function	$	949,590	
Standard deviation of objective function	$	306,850	

Run summary file: Multiple Enterprises-Optimal number of AUY.xls operator) in 79 percent of the years (Table 12). When yearlings were purchased an average 2,916 head (850 AUY) would be purchased.

Panel C in Table 12 shows averages for economic variables with unrestricted and flexible stocking rates. The average annual net return was estimated to be $116,040 ($130/AUY) which is over four times more than the net return for the current 345 AUY stocking rate with management as a cow/calf ranch ($26,186). Average annual production expenses average over $1 million/year with the majority of this cost to purchase yearlings. About 23 percent of the iterations had negative annual net returns, requiring a subsidy from the wildlife enterprise. Additional borrowing was required about 0.40 percent of the time.

The substantial increase in net returns does not occur without accepting a great deal more risk. Figure 11 plots average annual net returns and the standard deviation of net returns for the scenarios described thus far and for other runs with increasing levels of the allowed upper stocking rate. In each case stocking rate was defined to be flexible downwards and the optimal cow herd size was estimated to be between 189 and 255 head (Table 13), decreasing slightly over the 40-year planning period. By harvesting additional forage in favorable years with yearlings net annual returns are highly variable, and increasing in variability as the ranch manager is willing to stock at higher and higher levels during favorable production years. Fixed costs are spread over more AUY as the upper-bound stocking rate increases and this also contributes to the increasing average in net returns. With the current conservative

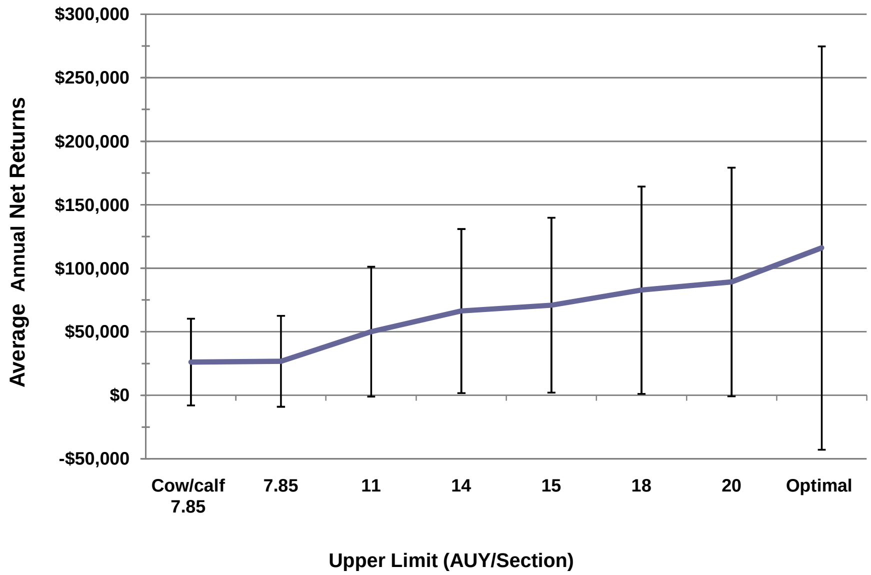


Figure 11. Average annual net returns from alternative scenarios.

7.85 AUY/section stocking rate the variability of net returns (risk) is at a minimum and so is the average annual net return.

Table 13. Optimal economic returns at alternative maximum stocking rates.

Maximum Total AUY	**Cow/calf 345**	**345**	**484**	**616**	**660**	**703**	**792**	**880**	**Optimal**
maximum AUY/Section	**7.85 AUY**	**7.85 AUY**	**11 AUY**	**14 AUY**	**15 AUY**	**16 AUY**	**18 AUY**	**20 AUY**	**AUY**
Production Variables									
Average number of total AUY	341	340	469	566	595	621	671	712	890
Average brood cows	240	194	248	254	251	249	241	234	189
Percent of years yearlings purchased	0	59%	61%	61%	61%	61%	61%	61%	58%
Average yealings purchased	0	279	495	870	1007	1,138	1,407	1,638	2,916
Percent of years forage was leased to an outside yearling operator	0%	19%	21%	22%	22%	22%	22%	22%	21%
Average number of AUMs leased	0%	948	1,536	2,556	2,964	3,348	4,044	4,644	6,888
Percent of years forage was leased	21%	20%	29%	35%	37%	39%	42%	45%	56%
Average amount of forage leased	2,618	2,556	3027	3,220	3,266	3,324	3,504	3,624	4,959
Percent of years maximum forage leased	0%	0%	4%	7%	8%	8%	10%	13%	39%
Annual Net Returns ($)									
Average	26,186	26,834	50,143	66,375	70,948	75,132	82,771	89,224	116,040
per AUY	77	79	107	117	119	121	123	125	130
Maximum	129,329	154,213	234,774	311,111	337,034	362,368	414,700	466,398	1,326,918
Minimum	-80,576	-84,749	-98,513	-105,712	-107,967	-110,370	-115,298	-119,974	-176,972
Standard deviation	34,106	35,874	51,131	64,654	68,857	73,013	81,605	89,981	158,869
Objective Function ($)									
Average	326,015	357,587	632,710	838,086	898,349	953,268	1,055,266	1,140,583	1,487,377
Maximum	475,287	517,490	838,241	1,162,459	1,263,556	1,351,804	1,527,988	1,674,886	2,627,048
Minimum	98,675	147,675	391,247	564,001	608,795	650,704	731,065	780,435	949,590
Standard deviation	73,004	72,977	100,531	132,311	143,257	153,873	174,701	193,161	306,850

Sensitivity Analysis

Economic Value of Additional Wildlife Income

Sensitivity analysis was carried out to estimate the economic value of the additional wildlife income and results are presented in Table 14. The Corona Ranch received $35,000/annum from wildlife income (in 2007). When the model was executed without wildlife income it reduced annual livestock economic return by $2,250. There was no substantial difference in the average number of total AUY and brood cows.

Alternative Forage Cost

Alternative forage cost values were evaluated to estimate the impact of higher value forage cost on livestock production and annual net returns (Table 15). When the forage cost/AUM increased from $20 to $30/AUM at $5 interval, the average total AUY and brood cow numbers were decreased considerably. But at the same time, the percent of time yearling were purchased from the market decreased by only 4 percent, because yearlings would only be purchased during favorable production years. The annual net return was decreased about $7,400 when the forage cost increase from $20 to $25/AUM. As forage cost increases further to $30/AUM, the livestock business would lose about 19 percent ($13,740) in annual net returns from its original annual net return. Though the ranch would optimally reduce considerably the level of herd size (9 percent reduction) when the forage cost increased about 50 percent ($20 to $30/AUM) it still maintained about 91 percent of the original herd size. This suggests that even at $30/AUM it would be profitable to maintain the livestock inventory.

Table 14. Economic value of additional wildlife income for multiple enterprises.

		With wildlife income	Without wildlife income
Maximum Total AUY		**660 AUY**	**660 AUY**
Maximum AUY/Section	**Unit**	**15 AUY**	**15 AUY**
Production Variables			
Average number of total AUY	AUY	595	593
Average brood cows	head	251	244
Percent of years yearlings purchased	%	61%	62%
Average yearlings purchased	head	1007	1,035
Percent of years forage was leased to an outside yearling operator	%	22%	22%
Average number of AUMs leased	AUM	2,964	3,072
Percent of years forage was leased	%	37%	37%
Average amount of forage leased	AUM	3,266	3,252
Percent of years maximum forage leased	%	8%	7%
Annual Net Returns			
Average	$	$70,948	$68,694
Change	$		-$2,255
Percent change	%		3.18%
Per AUY	$	$119	$116
Maximum	$	$337,034	$335,828
Minimum	$	-$107,967	-$103,070
Standard deviation	$	$68,857	$66,649
Objective Function			
Average	$	$898,349	$873,166
Maximum	$	$1,263,556	$1,256,057
Minimum	$	$608,795	$352,059
Standard deviation	$	$143,257	$167,000

Table 15. Economic value of low forage cost for multiple enterprises.

		Leased forage at $20/AUM	Leased forage at $25/AUM	Leased forage at $30/AUM
Maximum Total AUY		**660 AUY**	**660 AUY**	**660 AUY**
Maximum AUY/Section	**Unit**	**15 AUY**	**15 AUY**	**15 AUY**
Production Variables				
Average number of total AUY	AUY	595	569	541
Average brood cows	head	251	212	166
Percent of years yearlings purchased	%	61%	58%	57%
Average yearlings purchased	head	1007	1,160	1320
Percent of years forage was leased to an outside yearling operator	%	22%	23%	24%
Average number of AUMs leased	AUM	2,964	3,432	4,080
Percent of years forage was leased	%	37%	30%	24%
Average amount of forage leased	AUM	3,266	3,047	2,667
Percent of years maximum forage leased	%	8%	4%	2%
Annual Net Returns				
Average	$	$70,948	$63,540	$57,208
Change	$		$7,409	$13,740
Percent change	%		10.44%	19.37%
per AUY	$	$119	$112	$106
Maximum	$	$337,034	$337,034	$339,212
Minimum	$	-$107,967	-$133,292	-$142,471
Standard deviation	$	$68,857	$73,560	$76,529
Objective Function				
Average	$	$898,349	$820,267	758,593
Maximum	$	$1,263,556	$1,227,502	1,202,132
Minimum	$	$608,795	$453,581	312,064
Standard deviation	$	$143,257	$163,767	179,303

MANAGEMENT AND PRODUCTION RECOMMENDATIONS

The linear programming analysis used to evaluate optimal production and marketing strategies for the Corona Ranch assumes upfront knowledge about future prices and levels of annual forage production. A Monte-Carlo procedure was used whereby average production strategies are considered across 4,000 different beef price and production situations. While the deterministic nature of the multi-period LP model is limiting in that a ranch manager does not have upfront price and production knowledge as assumed, the analysis very clearly indicates several management adjustments that could be taken to improve the profitability of the Corona Ranch and similar New Mexico ranches.

The major recommendation is that a flexible grazing strategy similar to that recommended by Dahl (1963) be adopted. As he described, grazing programs that minimize the effects of wide forage fluctuations will graze the range with a core breeding herd that is set below what would be detrimental to the range during drought years. Any excess forage produced in average or above average years would be utilized by purchased animals.

A core cow herd size of 345 AUY (243 mature brood cows, 34 cull cows, 16 bulls, and 37 replacement heifers) is approximately the profit maximizing number to have on the Corona Ranch. At this level, forage production can be expected to be less than adequate for the core herd 21 percent of the time, requiring leasing of outside forage and/or herd reduction. The key is that during favorable production years additional yearlings need to be purchased to take advantage of the added forage. It is important to incorporate the flexibility that yearling purchases add to the ranch business. Similar to the findings of Ash et al. (2000) in Australia, the conservative stocking rate as now practiced on the Corona Ranch does not adjust stocking rates upward during favorable production years and consequently receives relatively low economic returns in good years due to lost opportunity costs.

The potential increase in net returns by adding yearlings depends on the degree to which advantageous production years can be estimated and anticipated, and actions taken to harvest the added AUMs of grazing capacity. Hart (1991) notes that to take advantage of flexible profit-maximizing stocking rates requires that early and accurate stocking rate decisions must be made. This requires an accurate prediction of how much forage will be available for the year, thus requiring an accurate weather forecast. He notes that in the northern High Plains of Wyoming forage production is primarily determined by precipitation in March, April, and May and with yearlings typically entering the pasture in May, annual forage production is largely known as the stocking decision is made. This is not the situation for the ranges of the southwest where warm season (C4) grasses predominate. On the Corona Ranch, grass growth does not typically commence until the summer rains of June, July and August. As noted by Ash et al. (2000), adopting a flexible stocking rate outperforms the conservative stocking rate but requires considerably better herd management and marketing skills because an error in judgment can negatively impact animal performance, economic returns, and the grazing resource.

Assuming outside forage can be leased for $20/AUM it is generally more profitable to maintain the cow herd through drought periods by leasing outside forage than it is to reduce cow numbers. Additional sensitivity analysis indicated this would still be the case if forage leased for $30/AUM, provided a cow/calf enterprise were the only production option. If yearlings are added as a production alternative then the least cost adjustment to drought would be a shift from a cow/calf enterprise to yearlings, and yearlings would not be purchased during this and subsequent drought periods. It would not be profitable to once again return to the cow/calf enterprise. "Overgrazing" was not considered in the analysis and the options considered were to reduce numbers or lease outside forage so as to adequately meet annual forage demands. The Bement (1969) stocking rule was enforced where 336 kg/ha of herbaceous material had to remain at the end of the grazing season. This residual would maximize animal performance and sustain forage resources (Bement 1969).

Expected net economic returns from a cow/calf enterprise versus a purchased yearling enterprise are nearly identical with the costs, prices, and production rates defined in the LP analysis. Yearlings are generally considered to be more risky because of variable rates of gain and unknown sale prices. Yet, incorporating this annual enterprise on the ranch would provide grazing flexibility that is not available with a cow/calf enterprise alone.

Selling calves in the fall as weaned calves (as practiced on the Corona Ranch) was found to be more profitable then carrying calves over for sale the following fall as yearlings. None of the price situations simulated by the beef price model resulted in carry-over yearlings being more profitable than selling weaned calves. Yearling rates of gain would have to be better than the 0.8 lb/head/day (0.36 kg/head/day) assumed in the analysis.

It is typical for western ranchers to raise their own replacement heifers, as is practiced on the Corona Ranch. This practice was found to be more profitable than purchasing cows for replacement and building of herd numbers. Cows were purchased only 0.5 percent of the time when relatively low bred cow prices were simulated.

Additional efforts to monitor and predict available forage resources will need to occur on the Corona Ranch but the potential economic return from these efforts are estimated to be substantial. Economic returns for the ranch and other New Mexico ranchers is greatly affected by managements ability to forecast and incorporate rainfall and forage production into stocking decisions.

APPENDIX

Appendix A: Linear Programming Model

```
/*
*****************************************************************************
*              Corona Ranch Multiperiod Linear Programming Model              *
*                                                                             *
*                  Multiple Enterprises with 345 AUY Maximum                  *
******************************************************************************
$Title Corona Ranch Model
$ONTEXT
Text Block can go here
$OFFTEXT

$OFFSYMLIST OFFSYMXREF

file returns /base_returns.txt/;            returns.pc=5;
* Returns is a file that summarizes costs and returns by year
file foragsum /base_land.txt/;              foragsum.pc=5;
* Foragsum is a file that summarizes forage use by year
file raisesum /base_raise.txt/;             raisesum.pc=5;
* Raisesum is a file that summarizes the number of raised animals by year
file risum /base_objfn.txt/;               risum.pc=5;
* Filesum is a file that summarizes the Objective Function (ranch income) by
 year
file lndsum /base_landuse1.txt/;             lndsum.pc=5;
* Lndsum is the file that summarizes seasonal landuse by year
file feedsum /base_feeduse.txt/;             feedsum.pc=5;
* Feedsum is a file that summarizes seasonal feed use by year
file haysum /base_haysale.txt/;             haysum.pc=5;
* haysum is a file that summarizes hay sales use by year

Scalars  totdays         Total days defined by various seasons
         calfcrop        Calf Crop Percentage at birth   /0.86/
         minrepl         Required min cow repl rate      /0.12/
         Bullrepl        Required bull replacement rate  /0.14/
         minhyear        Required min heifers for sale   /0.10/
         maxrepl         Max % heifer calves kept        /0.50/
         cowbull         cow to bull ratio               /20.0/
         numhorse        number of horses on ranch       /7.0/
         Rho             discount rate                   /0.07/
         Commiss         Commission % cost to sell cow   /0.03/
         Yardage         Yardage and trans Charge($ per day)  /1.50/
         Salefeed        Sale feed charge ($ per cwt)    /.30/
         Offranch        Off ranch income                /35000/
         Family          family living allowance         /000/
         Fixed           Fixed ranch expenses            /43921/
         Iwealth         Initial cash position           /35000/
         Frugal          % of cash transferred           /0.50/
* Endval is average buy price of cow
         Endval          final year net return           /75/
         Stloanr         Short term borrowing rate       /0.09/
         oploanr         opportunity loan rate           /0.075/
         Savrate         Interest return on Savings acct /.03/

```

```
* Forage parameters
         Residual        Residual forage amount(kg_ha)   /336/
         Harvest         percent of forage harvestable   /1.0/
         AUMeq           lbs_acre per AUM                /800/
         foragedecay     loss of carryover forage        /.87/
         leasforpric     lease out forage price $_AUM    /16/
         leasforcost     lease out forage cost $_AUM     /2.41/
;
* Change years to match price data set
Set T Time periods /year01*Year40/
    TLAST(T)  Last Period

*If you have different seasons, there are changes throughout the model that must be made
Set seasonON grazing season start date /seas1*seas7/
Set iter iteration /iter001*iter100/
set Type AUM type 1=kg_ha 2=aum_ac /1*2/
Set season(seasonON) grazing season /seas1*seas6/
*If you have different land or crop types, there are changes throughout the model that must be made
Set land types of land available
    /adamscom,Johnson, lanepast, A_B_past, Mpasture,IJ_Past, Ortiz, sheep, ram, Leased, purchalf/
Set Crop(land) /purchalf/
Set landitem /number, cropyld, conver, RELPROD, forcost /
Set date1 /m, d, y, serial, days, months /
Set livclass /broodcow, cullcow, bull, horse, scalf, hcalf,
     syear, hyear, purscalf, purhcalf, rephcalf, rephyear, buybcow, sellbcow, buybull/
Set livecl(livclass) /cullcow, bull, scalf, hcalf, syear, hyear,
     purscalf, purhcalf, sellbcow/
Set livpara /buywt, salewt, deathlss, animcost/
Set Costsum /forcost, animcost, loancst, totcost, gross, repgross,
    net, netdisc, cashtr, accumsav, stborrow, repayst/
Set out1 /acres, slack, total, shadow, cost, kgha, aumac, aums/


parameter buypric(T,livclass);
parameter salepric(T,livclass);
parameter Econ(iter,T,costsum)      Economic Variables;
Parameter Landsum(iter,Land,T,out1) Land Use Summary;
Parameter Landseas(iter,Land,T,season)  Seasonal land use summary;
Parameter Feedseas(iter,Crop,T,season) Seasonal Crop use summary;
*Parameter haysale(iter,Crop,T)          crop sales summary;
Parameter anim(iter,T,Livclass)     raised animals summary;
parameter CATAUY1(iter,T)           Cattle AUY on ranch;
parameter LEASAUY(iter,T)           AUY leased to others;
parameter TOTAUY1(iter,T)           total AUY on ranch;
parameter HV(T,iter,Type)           Normal Distribution Forage estimate;
parameter AUMVAL(LAND,T)            aums available by year;
parameter AUMAC1(Land,T,iter)       Acres per AUM by year and forage condition;
parameter ri(iter)                  Ranch Income Summary;
parameter MS(iter)                  Model status by iter;

```

```
*The following Include statments must be changed for location and name of your price file
*$Include "Z:\GAMS model\Chaves_Model\data\beefprice2005_5iter_10years.txt"
$Include "Z:\GAMS model\Chaves_Model\data\beefprice_2005_100iter_40years.txt"
display salep;
* compute the number of days in each grazing season and assure total
* is 365 or 366. Uses date functions from GAMs Model library calendar.gms.
* Season 7 must close out the year in the following year.
table onday(seasonON,date1)
                 m        d        y
seas1            3        1      2007
seas2            5        1      2007
seas3            6        1      2007
seas4           10        1      2007
seas5           11        1      2007
seas6           12        1      2007
seas7            3        1      2008
;
* "Serial" is number of days past Jan. 1, 1900
onday(seasonON,"serial") = jdate(onday(seasonON,"y"),
  onday(seasonON,"m"),onday(seasonON,"d"));
onday(seasonON,"days") $ (ord(seasonON)LT card(seasonON)) =
   onday(seasonON+1,"serial") - onday(seasonON,"serial");
onday(season,"months") = onday(season,"days")/30.41667;
totdays = sum(season, onday(season,"days"));
display onday;
if ((totdays = 365 or totdays = 366), display totdays;
else abort "Total season days not 365 or 366, adjust dates";
);
* put a one (1) in the seasons when grazed forages are to be available
table avail(land, season) seasonal forage availability
                 seas1   seas2   seas3   seas4   seas5   seas6
adamscom            1       1       1       1       1       1
Johnson             1       1       1       1       1       1
lanepast            1       1       1       1       1       1
A_B_past            1       1       1       1       1       1
Mpasture            1       1       1       1       1       1
IJ_past             1       1       1       1       1       1
Ortiz               1       1       1       1       1       1
sheep               1       1       1       1       1       1
ram                 1       1       1       1       1       1
Leased              1       1       1       1       1       1
```

```
;

* put a one (1) in the seasons when hay can be fed.
table cropaval(crop, season) seasonal crop feeding availability
                  seas1   seas2   seas3   seas4   seas5   seas6
purchalf            1       1                       1       1
;

* Enter aumac=1 when units are AUMs
* cropyld is tons per acre
* conver = conversion factor Tons to AUMs
* RELPROD = relative rangeland productivity

table forage(land,landitem) forage sources
             number      cropyld    conver    relprod   forcost
adamscom     2107                    2.42      1.00       1.37
Johnson      7937                    2.42      0.70       1.37
lanepast     3299                    2.42      0.94       1.37
A_B_past     1685                    2.42      0.77       1.37
Mpasture     1430                    2.42      0.52       1.37
IJ_past      4370                    2.42      0.74       1.37
Ortiz        2254                    2.42      0.85       1.37
sheep        3593                    2.42      1.00       1.37
ram          1437                    2.42      1.00       1.37
purchalf      100         1.0        2.42      1.00     200.00
Leased       6000                    2.42      1.00      20.00
;

display forage;
* Enter AU equivalencies for the animal class in each season
table aue1(livclass,season) AUE for animal classes by season in year T
                 seas1    seas2    seas3     seas4   seas5    seas6
broodcow         1.00     1.00     1.00      1.00    1.00      1.00
sellbcow         1.00     1.00     1.00      1.00    1.00      1.00
buybcow          1.00     1.00     1.00      1.00    1.00      1.00
cullcow          1.00     1.00     1.00      1.00
bull             1.25     1.25     1.25      1.25    1.25      1.25
horse            1.25     1.25     1.25      1.25    1.25      1.25
scalf
hcalf
purscalf                  0.70     0.70
purhcalf                  0.70     0.70
syear                                        0.50    0.50      0.60
hyear                                        0.50    0.50      0.60
rephcalf                                     0.50    0.50      0.50
rephyear                                     0.50    0.50      0.50
;


table aue2(livclass,season) AUE for animal classes by season in year T+1
                seas1     seas2    seas3     seas4   seas5     seas6
broodcow
cullcow
bull
```

```
horse
scalf
hcalf
purscalf
purhcalf
syear            0.70     0.70     0.75
hyear            0.70     0.70     0.75
rephcalf
rephyear         0.70     0.70      0.75      1.00    1.00      1.00
;


table Animal(livclass,livpara) sale weights and costs by animal class
              buywt     salewt   deathlss     animcost
broodcow                          0.01          58.50
cullcow                 10.0      0.01          58.50
bull                    3.33      0.01           0.0
* assumptions for bull 2000 lb but kept 6 years so (20.0/6) = 3.33
scalf                   5.20      0.03           0.0
hcalf                   4.80      0.03           0.0
syear          5.20      8.10      0.05         117.0
hyear          4.80      7.70      0.05         117.0
* owned yearling death loss should include both calf and yearling losses
purscalf       4.00      6.60      0.03          82.0
purhcalf       4.00      6.50      0.03          82.0
rephcalf                          0.03           0.0
rephyear                          0.02          58.50
buybcow        1.00
sellbcow                1.00      0.01
buybull        1.00
;

display Animal;

PARAMETERS
           DF(T)      Discount factor at time T;
           DF(T) = (1+RHO)**(-1*(ORD(T)));
display DF;
           TLAST(T)  = YES$(ORD(T) EQ CARD(T));
DISPLAY TLAST;

*Calculate AUMS per Acre assuming normal distribution;
*Harvestable forage after field wastages by different factors;
*Harvestable forage is assumed to be 75% of the standing crop and can be changed;
******************** Calculate forage available by year *********************;
          HV(T,iter,"1") = normal (651,200) ;
          HV(T,iter,"2") = max (((HV(T,iter,"1") - residual) *harvest * 2.2046) / (2.47*AUMEQ),0);
          display HV;
          AUMAC1(Land,T,iter)=HV(T,iter,"2");
          AUMAC1(crop,T,iter)=eps;
          AUMAC1("Leased",T,iter)= 1.0;
          display AUMAC1;
```

```

POSITIVE VARIABLES
     Landuse(land,season,T)        Acres or AUMS of land used in year T
     Leasefor(season,T)            Lease an AUM of forage at year T
     CATAUY(T)                     cattle AUY at time t
     TOTAUY(T)                     total AUY at time t
     slacklnd(Land,T)              Unused land resources
     raise(livclass,T)             Raise livestock of class in year T (head)
     selllive(livecl,T)            Sell livestock of class in year T (cwt)
*    sellcrop(crop,T)              Sell forage crop in year T
     feedcrop(Crop,season,T)       Feed forage crop AUMs in year T
     FORCOST(T)                    Forage harvest costs
     ANIMCOST(T)                   Animal production costs
     GROSS(T)                      Gross livestock returns
     STBORROW(T)                   Short Term Borrowing
     REPAYST(T)                    Repay Short Term Loan
     LOANCST(T)                    Principal and Interest Payments
;
VARIABLES
     Ranchinc                      Ranch Income
     NET(T)                        Net livestock returns undiscounted
     NETDIS(T)                     Net livestock returns discounted
     CASHTR(T)                     Cash transfered to next period
     AccumSav(T)                   Accumulated Savings
     TERM                          Terminal Value
;

EQUATIONS
      LANDAVAL(LAND, T)    Land Use Equation
      AUMAVAIL1(T, season) Total AUMS available Year 1
      AUMAVAIL2(T, season) Total AUMS available season 1 and 2 year t
      AUMAVAIL3(T, season) Total AUMS available season 3 to 6 year t
      LEASEFORAGE(T,season)  season forage lease season 2 and 3
      CATTLEAUY(T)         total cattle AUY at year t
      TOTALAUY(T)          total AUY at year t
      CROPPROD(crop,T)    Production of crops
      BULLRAT(T)          Set Bull to cow ratio
      CULLRATC(T)         Set cull cow to raised cow ratio
      COWTRAN(T)          Cow transfer between years
      BULLTRAN(T)         Bull transfer between years
      REPTRAN(T)          Calf replacement transfer to yearling replacement
      MINREPLC(T)         Minimum cow replacement rate
      MAXREPLC(T)         Maximum cow replacement rate
      MINHYRC(T)          Minimum additional replacements sold
      RSCALFC1(T)         Raise steer calf ratio year 1
      RSCALFC2(T)         Raise steer calf ratio year NE 1
      RHCALFC1(T)         Raise heifer calf ratio year 1
      RHCALFC2(T)         Raise heifer calf ratio year NE 1
      SALES(livclass,T)   Sales transfer
      COSTFORC(T)         Forage Production costs at T
      COSTANIC(T)         Animal production costs at T
      GROSSRET(T)         Gross Livestock returns at T
      NETRET(T)           Net Livestock returns at T
      NETRETD(T)          Discounted net returns at T
```

```
      INCOME              Ranch Income definition
      CASHSOUR(T)         Transfers of Cash
      SAVING1(T)          Accumulated Savings at time 1
      SAVING2(T)          Accumulated Savings at time T
      STREPAY(T)          Force repayment of Short-term loans
      LOANPAY(T)          Loan Repayment Calculation
      TERMVAL             Terminal Value (Net R infinitely discounted)
;

*Forage demand and supply equations

LANDAVAL(LAND,T)..  SUM(season,landuse(land,season,T))+ slacklnd(land,T)=E=
    forage(land,"number");
CROPPROD(CROP,T).. sum(season,feedcrop(crop,season,T))=L=
    sum(season,landuse(crop,season,T))* forage(crop,"cropyld");

AUMAVAIL1(T, season)$(ORD(T) EQ 1)..  SUM(livclass,
raise(livclass,T)*aue1(livclass,season))*
    onday(season,"months")
    + SUM(livclass, raise(livclass,T-1)* aue2(livclass,
season))*onday(season,"months")
   + Leasefor(season,T)
    =L= SUM(land,AUMVAL(land,T)*landuse(land,season,T)* avail(land,season))
    + SUM(crop,feedcrop(crop,season,T)*forage(crop,"conver")*
     cropaval(crop,season));

* Aums during season1 and season2 are carried from previous year.
AUMAVAIL2(T, season)$(ORD(T) GT 1 and ORD(Season) LT 3)..  SUM(livclass,
raise(livclass,T)*aue1(livclass,season))*
    onday(season,"months")
    + SUM(livclass, raise(livclass,T-1)* aue2(livclass,
    season))*onday(season,"months")
    + Leasefor(season,T)
    =L= SUM(land,AUMVAL(land,T-1)*landuse(land,season,T-1)*
    avail(land,season))*foragedecay
    + SUM(crop,feedcrop(crop,season,T)*forage(crop,"conver")*
    cropaval(crop,season));

* Aums during season3  to season t are produced this year.
AUMAVAIL3(T, season)$(ORD(T) GT 1 and ORD(Season) GE 3)..  SUM(livclass,
 raise(livclass,T)*aue1(livclass,season))*
    onday(season,"months")
    + SUM(livclass, raise(livclass,T-1)* aue2(livclass,
    season))*onday(season,"months")
    + Leasefor(season,T)
    =L= SUM(land,AUMVAL(land,T)*landuse(land,season,T)* avail(land,season))
    + SUM(crop,feedcrop(crop,season,T)*forage(crop,"conver")*
     cropaval(crop,season));

LEASEFORAGE(T,season)$(ORD(Season) EQ 3)..
    onday(season,"months")*leasefor(season-1,T)
     =E= onday(season-1,"months")*leasefor(season,T);

CATTLEAUY(T).. CATAUY(T) =E= sum(season, sum(livclass,
```

```
  raise(livclass,T)*aue1(livclass,season))*
 onday(season,"months")+ SUM(livclass, raise(livclass,T-1)* aue2(livclass,
 season))*
onday(season,"months"))/12;
TOTALAUY(T).. TOTAUY(T) =E= sum(season,Leasefor(season,T)/12) + CATAUY(T);
*Cattle transfer equations
COWTRAN(T)$(ORD(T) GT 1).. raise("broodcow",T) + raise("cullcow",T) +
     raise("sellbcow",T)
    =L= raise("broodcow",T-1)*(1-Animal("broodcow","deathlss")) +
    raise("rephyear",T-1)*(1-Animal("rephyear","deathlss")) +
 raise("buybcow",T);
BULLTRAN(T)$(ORD(T) GT 1).. raise("bull",T) =L= (1-bullrepl)*raise("bull",T-
 1)*(1-animal("bull","deathlss"))
 + raise("buybull",T) ;
REPTRAN(T)$(ORD(T) GT 1).. raise("rephcalf",T-1)*(1-
    animal("rephcalf","deathlss"))
    =E= raise("rephyear",T);
BULLRAT(T)..  raise("broodcow",T) + raise("cullcow",T) + raise("rephyear",T)
    =E= cowbull*raise("bull",T);
CULLRATC(T)..  raise("cullcow",T) =e= minrepl*(raise("broodcow",T)+
    raise("rephyear",T));
MINHYRC(T)..  Raise("hyear",T) =G= minhyear*raise("rephyear",T);
MINREPLC(T)$(ORD(T) GT 1).. minrepl*(raise("broodcow",T)/(1-
  Animal("broodcow","deathlss"))+
    raise("cullcow",T)/(1-Animal("cullcow","deathlss"))) =L=
    raise("rephyear",T-1)*(1-Animal("rephyear","deathlss"))+ raise("buybcow",T);
MAXREPLC(T).. raise("rephcalf",T) =L= maxrepl *(raise("hcalf",T) +
 raise("hyear",T)+ raise("rephcalf",T));
RSCALFC1(T)$(ORD(T) EQ 1)..  raise("scalf",T) + raise("syear",T) =L=
 calfcrop/2*(raise("broodcow",T)
+ raise("rephyear",T));
RSCALFC2(T)$(ORD(T) GT 1)..  raise("scalf",T) + raise("syear",T) =L=
 calfcrop/2*(raise("broodcow",T)
+ raise("rephyear",T-1));
RHCALFC1(T)$(ORD(T) EQ 1).. raise("hcalf",T) + raise("hyear",T) +
    raise("rephcalf",T) =L=
    calfcrop/2*(raise("broodcow",T) + raise("rephyear",T)) ;
RHCALFC2(T)$(ORD(T) GT 1).. raise("hcalf",T) + raise("hyear",T) +
    raise("rephcalf",T) =L=
    calfcrop/2*(raise("broodcow",T) + raise("rephyear",T-1)) ;
*Livestock sales and costs
SALES(livecl,T).. selllive(livecl,T) =L= (1-Animal(livecl,"deathlss"))*
    Animal(livecl,"salewt")* raise(livecl,T);
COSTFORC(T).. FORCOST(T) =E= SUM(season,SUM(land,landuse(Land,Season,T)*
  forage(land,"forcost")))
  + SUM(season,Leasefor(Season,T))*leasforcost ;
COSTANIC(T).. ANIMCOST(T) =E=
  (SUM(livclass,animal(livclass,"animcost")*raise(livclass,T))*(1+oploanr/2) +
   SUM(livclass,buypric(T,livclass)*animal(livclass,"buywt") *
     raise(livclass,T))*(1+oploanr))
    - raise("syear",T)*buypric(T,"syear")*animal("syear","buywt")
```

```
   - raise("hyear",T)*buypric(T,"hyear")*animal("hyear","buywt");
* purchased animal interest charge 6 months.
GROSSRET(T).. GROSS(T) =E=
SUM(livecl,selllive(livecl,T)*salepric(T,livecl))+leasforpric*sum(season,
leasefor(season,T));
LOANPAY(T)..  LOANCST(T) =E= (1+Stloanr)*repayst(T);
CASHSOUR(T).. CASHTR(T) =E= Frugal*(NET(T) + Offranch - family);
NETRET(T).. NET(T) =E= GROSS(T)-FORCOST(T)-ANIMCOST(T)-LOANCST(T) - fixed;
NETRETD(T).. NETDIS(T) =E= NET(T)*DF(T);
INCOME ..  Ranchinc =e= sum(T, NETDIS(T));
*+ TERM;
SAVING1(T)$(ORD(T) EQ 1).. AccumSav(T) =e= IWEALTH + NET(T) + OFFRANCH
    - Family + STBORROW(T);
SAVING2(T)$(ORD(T) GT 1).. AccumSav(T) =e= Frugal*AccumSav(T-1)*(1 + savrate)
    + NET(T) + OFFRANCH - Family + STBORROW(T);
STREPAY(T).. STBORROW(T-1) =L= REPAYST(T);


*Terminal Value - need to calculate the gross margin/head.  Divide total gross
 margin
*by expected number of brood cows, cull cows, replacement heifer calves, and
*replacement heifer yearlings.
TERMVAL(TLAST)..  TERM =E= ((raise("BROODCOW",TLAST)+raise("CULLCOW",TLAST)
     +raise("rephyear",TLAST)+raise("rephcalf",TLAST))*ENDVAL)/RHO*(1-
      1/((1+RHO)**CARD(T)));

**************** Set bounds for selected variables **********************

* accumsav is the minimum accumulated savings
* the year01 numbers set an initial endowment of animals
* the year40 numbers limit the number of replacements for the terminal value

accumsav.lo(T)= 10000.;
*stborrow.up(T)=100000;
stborrow.up(T)$(ORD(T) EQ CARD(T)) = 0;
*slacklnd.up("adamscom",T)=0;
raise.up("sellbcow",T)$(ORD(T) EQ 1) = 0;
*raise.up("buybcow",T)=1000;
*raise.lo("broodcow",T) = 0;
raise.fx("broodcow",T)$(ORD(T) EQ 1) = 194;
raise.fx("rephyear",T)$(ORD(T) EQ 1) = 74;
*raise.up("purhcalf",T)$(ORD(T) EQ 1) = 10;
*raise.up("purscalf",T)$(ORD(T) EQ 1) = 10;
*raise.up("hyear",T)$(ORD(T) EQ 1) = 0;
*raise.up("syear",T)$(ORD(T) EQ 1) = 0;
*raise.up("rephcalf",T)$(ORD(T) EQ CARD(T)) = 60;
raise.fx("horse",T)=7;
ranchinc.up=5000000;

***************************************************************************
*Restrict forage leasing to seasons 2 and 3
leasefor.up("seas1",T) = 0;
leasefor.up("seas4",T) = 0;
leasefor.up("seas5",T) = 0;
```

```
leasefor.up("seas6",T) = 0;
* Restrict to specific carrying capacity (AUY/section0
TOTAUY.UP(T) = 345;
*************************************************************************
* You can change the name of the model to match your area.  Need to change the
* name in the solve equation as well.
model Chavebase base level model / all /;
*option lp=gamschk;
option lp=minos5;
option limrow =40;
option limcol = 40;
option SOLPRINT=ON;
****************** Start Loop***********Start Loop***************************
loop(iter,
salepric(T,"cullcow")  = salep(iter,T,"cullcow");
salepric(T,"bull")     = salep(iter,T,"bull");
salepric(T,"scalf")    = salep(iter,T,"scalf");
salepric(T,"hcalf")    = salep(iter,T,"hcalf");
salepric(T,"syear") = salep(iter,T,"syear");
salepric(T,"hyear") = salep(iter,T,"hyear");
salepric(T,"purscalf") = salep(iter,T,"purscalf");
salepric(T,"purhcalf") = salep(iter,T,"purhcalf");
*assumes %commission of (Commiss), daily yardage fee of YARDAGE, Feed of
* $SALEFEED/cwt
*salepric(T,"sellbcow") = (salep(iter,T,"buybcow")*calfcrop + (1-calfcrop)*
* (salep(iter,T,"cullcow")*Animal("sellbcow","salewt")))*(1-Commiss)
*  - Yardage - salefeed*Animal("sellbcow","salewt")  ;
salepric(T,"sellbcow") = salep(iter,T,"cullcow")*Animal("sellbcow","salewt");
buypric(T,"buybcow") = salep(iter,T,"buybcow");
buypric(T,"buybull") = 154.09 + 2.0549*buypric(T,"buybcow");
buypric(T,"purscalf") = salep(iter,T,"scalf");
buypric(T,"purhcalf") = salep(iter,T,"hcalf");
buypric(T,"syear") = salep(iter,T,"scalf");
buypric(T,"hyear") = salep(iter,T,"hcalf");
AUMVAL(LAND,T) = AUMAC1(Land,T,iter)*Forage(land,"relprod");
display AUMVAL;
display buypric;
display salepric;
* Make sure the second word matches your model name specified above in the MODEL statement.
SOLVE Chavebase USING LP MAXIMIZING ranchinc ;
display ranchinc.l;
```

```
display
     landuse.l
     raise.l
     feedcrop.l
     leasefor.l
*    raise.up
     selllive.l
*    sellcrop.l
;

Econ(iter,T,'forcost')  = forcost.L(T);
Econ(iter,T,'animcost') = animcost.L(T);
Econ(iter,T,'loancst')  = loancst.L(T);
Econ(iter,T,'totcost')  = forcost.L(T) + animcost.L(T) + loancst.L(T);
Econ(iter,T,'gross')    = gross.L(T);
Econ(iter,T,'Repgross') = raise.L("rephcalf",T)*salepric(T,"hcalf")*
animal("hcalf","salewt")+ raise.L("rephyear",T)*salepric(T,"hyear")*
animal("hyear","salewt");
Econ(iter,T,'Net')      = Net.L(T);
Econ(iter,T,'netdisc')  = Netdis.L(T);
Econ(iter,T,'cashtr')   = cashtr.L(T);
Econ(iter,T,'accumsav') = accumsav.L(T);
Econ(iter,T,'stborrow') = stborrow.L(T);
Econ(iter,T,'repayst')  = repayst.L(T);

display Econ;


if ((totdays = 365 or totdays = 366), display totdays;
else abort "Total season days not 365 or 366, adjust dates";
);

Landsum(iter,Land,T,'acres')   = sum(season,landuse.L(land,season,T));
Landsum(iter,Land,T,'cost')  =
sum(season,landuse.L(land,season,T))*forage(land,"forcost");
Landsum(iter,Land,T,'Slack')  = slacklnd.L(land,T);
Landsum(iter,Land,T,'Total')  = sum(season,landuse.L(land,season,T)) +
slacklnd.L(land,T);
Landsum(iter,Land,T,'Shadow') = slacklnd.m(land,T);
Landsum(iter,Land,T,'kgha') = HV(T,iter,"1");
Landsum(iter,Land,T,'aumac')= AUMVAL(LAND,T);
Landsum(iter,Land,T,'AUMS')   = Landsum(iter,Land,T,'acres')*AUMVAL(Land,T);

CATAUY1(iter,T) = CATAUY.L(T);
LEASAUY(iter,T) = sum(season,Leasefor.L(season,T)/12);
TOTAUY1(iter,T) = TOTAUY.L(T);


Landseas(iter,Land,T,'seas1') = landuse.L(land,'seas1',T);
Landseas(iter,Land,T,'seas2') = landuse.L(land,'seas2',T);
Landseas(iter,Land,T,'seas3') = landuse.L(land,'seas3',T);
Landseas(iter,Land,T,'seas4') = landuse.L(land,'seas4',T);
Landseas(iter,Land,T,'seas5') = landuse.L(land,'seas5',T);
Landseas(iter,Land,T,'seas6') = landuse.L(land,'seas6',T);
```

```
Feedseas (iter,Crop,T,'seas1') = Feedcrop.L(crop,'seas1',T);
Feedseas (iter,Crop,T,'seas2') = Feedcrop.L(crop,'seas2',T);
Feedseas (iter,Crop,T,'seas3') = Feedcrop.L(crop,'seas3',T);
Feedseas (iter,Crop,T,'seas4') = Feedcrop.L(crop,'seas4',T);
Feedseas (iter,Crop,T,'seas5') = Feedcrop.L(crop,'seas5',T);
Feedseas (iter,Crop,T,'seas6') = Feedcrop.L(crop,'seas6',T);

*Haysale(iter,Crop,T) = sellcrop.L(crop,T);

anim(iter,T,"broodcow") = raise.L("broodcow",T);
anim(iter,T,"cullcow")  = raise.L("cullcow",T);
anim(iter,T,"bull")     = raise.L("bull",T);
anim(iter,T,"horse")    = raise.L("horse",T);
anim(iter,T,"scalf")    = raise.L("scalf",T);
anim(iter,T,"hcalf")    = raise.L("hcalf",T);
anim(iter,T,"syear")    = raise.L("syear",T);
anim(iter,T,"hyear")    = raise.L("hyear",T);
anim(iter,T,"purscalf") = raise.L("purscalf",T);
anim(iter,T,"purhcalf") = raise.L("purhcalf",T);
anim(iter,T,"rephcalf") = raise.L("rephcalf",T);
anim(iter,T,"rephyear") = raise.L("rephyear",T);
anim(iter,T,"buybcow")  = raise.L("buybcow",T);
anim(iter,T,"sellbcow") = raise.L("sellbcow",T);
anim(iter,T,"buybull")  = raise.L("buybull",T);

*Options display AUY;

ri(iter)=ranchinc.L;
MS(iter)=chavebase.modelstat;
);

* END iter loop with ); above

options decimals=1; display feedseas;
options decimals=1; display Econ;
options decimals=1; display Landsum;
options decimals=1; display anim;

put returns 'run' 'year' 'iter' ;
loop(costsum, put costsum.tl);
loop(iter,
loop(T,
 put / 'Base' T.te(T);
 put iter.te(iter);
loop (Costsum, put Econ(iter,T,costsum))));

put foragsum 'Run' 'Landtype' 'year' 'iter' ;
loop(out1, put out1.tl);
loop(iter,
  loop(land, loop(T,
    put /'Base'  Land.te(Land), T.te(T), iter.te(iter);
         loop(out1, put landsum(iter,Land,T,out1)))));
```

```
put lndsum 'Run' 'landtype' 'year' 'iter' ;
 loop(season, put season.tl);
 loop(iter,
   loop(land, loop(T,
 put / 'Base' Land.te(Land), T.te(T);
 put iter.te(iter);
 loop (season, put Landseas(iter,Land,T,season)))));

put feedsum 'Run' 'crop' 'year' 'iter'  ;
 loop(season, put season.tl);
 loop(iter,
   loop(Crop, loop(T,
 put /"Base" Crop.te(Crop), T.te(T);
 put iter.te(iter);
 loop (season, put Feedseas(iter,Crop,T,season)))));

put haysum 'Run' 'Crop' 'year' 'iter'  'Tonsold';
loop(iter,
  loop(crop, loop(T,
    put /"Base" Crop.te(Crop), T.te(T), iter.te(iter))));
*     put haysale(iter, crop,T))));

put raisesum 'Run' 'Year' 'iter' 'LEASAUY' 'CATAUY' 'TOTAUY';
loop(livclass, put livclass.tl);
loop(iter,
   loop(T, put /"Base" T.te(T);
put iter.te(iter);
*loop (T, put LEASEFOR(Season, T);
put LEASAUY(ITER,T);
put CATAUY1(ITER,T);
put TOTAUY1(ITER,T);
    loop(livclass, put anim(iter,T,Livclass))));

put risum 'Run' 'iter'  'ObjFun' 'Model Status';
loop(iter,
put /"Base" iter.te(iter), ri(iter),MS(iter));
/*
```

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