Beef cattle management decisions relating to drought in the Northern Great Plains
by Rosanne E Kruse

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal and Range Sciences
Montana State University

Abstract:
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Master of Science

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MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2002

APPROVAL

of a thesis submitted by

Rosanne E. Kruse

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

This research addresses the hypotheses that 1) spring precipitation data can be used to detect drought early in the growing season and 2) manipulating management strategies based on early detection of drought can have a positive effect on enterprise profitability. The Rangetek range model was used to simulate yearly forage data based on historical precipitation and temperature records from the Fort Keogh USDA-ARS Station near Miles City, Montana and the Manyberries Substation near Lethbridge, Alberta. Thirty years of climate data from Fort Keogh and 50 yr of climate and forage data from Manyberries were used to develop regression equations predicting annual forage production. The results suggest that April, May, and June precipitation reasonably predict forage production. Equations developed from simulated data did not find July precipitation to be significant. Although when utilizing the actual forage production data from Lethbridge July precipitation was a significant predictor, adding July precipitation did not increase the ability of the equation to detect emerging drought. These results indicate that forage production can reasonably be forecasted by July 1st. Two bio-economic models were parameterized to represent a range-based cow-calf production system in the Northern Great Plains. Treatments were factorially arranged where management, intensity of drought, purchased hay cost, and forage quality were evaluated for effects on system performance. The normal management (NM) scenario included no 'early' management changes to emerging drought. Cows were fed hay and/or purchased supplement to maintain performance, herd size, and average weaning weight. The early management (EM) scenario employed weaning calves at an average 90d of age. Treatments were evaluated based on feed costs, average calf weaning weight, ranch gross margin (gross margin – variable costs), and cumulative gross margin (ranch gross margin + net revenue from drylot calves). For all levels of drought, hay price, and forage quality EM had lower purchased feed costs and higher cumulative gross margins than NM. Most of the variation in gross margins between NM and EM strategies was reflected in higher feed costs for the NM scenario. Directly feeding early-weaned calves proved more efficient than feeding cows to produce milk to maintain calf performance.

CHAPTER ONE

INTRODUCTION

Beef cattle producers are faced with changing commodity markets, where there is increasing competition with the pork and poultry industries. Much of the success of these industries is due to marketing their products specifically to consumer demand and controlling many aspects of the production environment yielding more consistent quality. The beef industry has difficulty duplicating this model due to the variable nature of the production environment for beef cattle. Currently, there is a wide range in quality in retail products due to genetic and environmental variation. Due to weak cattle prices, decreased consumer demand, and competition for public use of land, cattle producers are forced to tighten management schemes in order to remain sustainable. Management now needs to control as many factors as possible that influence performance of beef cattle. The environment, or climate, is one of the most important, least controllable, and most erratic factors.

The Great Plains is characterized by erratic climate because of the location in the center of the continent. As a result of this climatic variation, a wide range of forage production is seen throughout the area and from year to year. It is more likely to see an extreme wet or dry year than the actual 'normal' (Jameson, 1987). Drought is an inevitable phenomenon in the Northern Great Plains.

The effects of drought usually come in successive stages. Plant production is almost solely dependent on the weather and any severe deviation from ‘normal’ will cause changes in yield. As forage yield is affected by dry weather, animals grazing those plants will decrease performance. In the case of poor management, or late changes in management to evolving droughts, changes in livestock performance can decrease the profitability of the operation.

Because effects of drought can damage not only the range resource, but also livestock performance and long-term sustainability, some measure of predictability, or a forecast of forage production, could help managers prepare for and respond to extremes. Finding predictors of forage production will allow the producer to make early, informed decisions. Proper management might avoid some of the negative effects of drought. Unfortunately, most ranchers are overly optimistic that the next day will bring much needed rain, and changing management will become unnecessary. When rain does not come or is short of the amount needed, ranchers are faced with feeding their cattle earlier than planned causing the need to purchase more feed to sustain the herd until the following spring. With this in mind, producers need a point within the growing season which they can 'read' the forage production and make well informed decisions that can enhance the long-term sustainability of the ranch.

Therefore, the objectives of this study were to identify a practical predictor of drought-induced forage yield reduction, and to evaluate practical alternative drought management strategies for their effects of beef cattle profits.

CHAPTER TWO

DROUGHT

Drought is an inevitable phenomenon in the Northern Great Plains. It is more likely to see an extreme wet or dry year than the actual 'normal' (Jameson, 1987). Cambell (1936) predicted that three out of ten years would experience drought in certain portions of the Great Plains. In 1951, Hurtt stated that rarely five years go by without a year of drought. Precipitation records at Miles City, Montana for 99 years [1879-1978] showed that a severe drought (one-third below-average precipitation) occurred every five to fifteen years (average nine years). A moist period (one-third above-average precipitation) occurred every 4 to thirty years (average 12 years) (White et al., 1978). Because of the frequency of the phenomena, drought is increasingly becoming accepted as a normal part of the farming system and not as a crisis (Foran and Smith, 1991).

Definition of Drought

Defining drought is a difficult task. Drought is related to precipitation and may be a result of several growing days without precipitation, low seasonal precipitation, or abnormally low annual precipitation for a particular year or period of years (Cook and Sims, 1975). Drought can then be described as a water shortage.

Shortages are differences between water demand and water supply (Yevjevich et al., 1978). This implies specification of the amount of water needed, which will depend on the nature and extent of animal and plant communities using the water. Therefore, drought cannot be divorced from the use to which water is put (Heathcote, 1973). With this in mind, Wilhite and Glantz (1985) divided drought into six different operational definitions determined by the use of water. The problem exists as different agencies with different goals and objectives begin to apply the term.

A concern for the beef producer is in distinguishing the differences between meteorological, hydrologic, and agricultural droughts. A meteorological classification of drought is generally measured on the degree of dryness, or a significant decrease from the climatologically expected and seasonably normal precipitation, during the calendar year (Newman, 1978; Wilhite and Glantz, 1985; Kulshreshtha, 1989). Hydrologic drought is an extended and more severe form of meteorological drought. Hydrologic drought is defined as naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels causing shrinkage and drying of streams and rivers, depletion of water stored in surface reservoirs and lakes, cessation of spring flows and decline of ground water levels (Yevjevich et al., 1978; Kulshreshtha, 1989; Le Houerou, 1996).

Agricultural drought is determined by a combination of factors. Kulshreshtha (1989) and Thurow and Taylor (1999) defined agricultural drought as the period when soil moisture and rainfall are inadequate during the growing season to; 1) support healthy forage growth to maturity, 2) prevent extreme forage stress and wilt, and 3) cause decreases in forage production. It is hard to quantify an agricultural drought because water deficits in plants, and the cause for such reductions, are dependent on environmental conditions and differences in the reactions of plants during the various stages of development (Herbel et al., 1972; Yevjevich et al., 1978; Wilhite and Glantz, 1985). Felch (1978) stated that an agricultural drought does not necessarily begin with the cessation of rain, but rather when available stored water in the soil cannot meet the evaporative demands of the atmosphere. Other weather events such as extreme temperature, low humidity, high winds, and others can by themselves produce drought-like conditions that affect plant production (Felch, 1978). One should note that agricultural drought is not only affecting range plants, but also the animals which feed on them. Smith and Foran (1992) described agricultural drought as a period during which palatable plant biomass is inadequate to satisfy livestock needs.

Although all of these concepts reflect the effects of prolonged weather conditions as measured by deficient moisture and increased evaporation, a manager needs to be discerning when collecting information relating to drought. Meteorological droughts do not necessarily coincide with periods of agricultural drought (Wilhite and Glantz, 1985). Meteorological and hydrologic drought are measured during the calendar year to determine the dryness or wetness of a year. This can be misleading and not predictive of emerging drought conditions on rangeland. Agricultural drought is mainly focused on the factors that affect plant growth and development. Hurtt (1951) stated that the 70 percent of the yearly precipitation that falls in the spring and summer growing season has a far greater influence upon forage production than the 30 percent that occurs in the non-growing season, so much so that shortage of precipitation in spring and summer is a true measure of drought. Therefore, the most useful information to a manager is measuring precipitation during the growing season.

The impact of a drought depends largely on society's vulnerability to drought at that particular moment (Wilhite and Glantz, 1985). The beef producer is continually vulnerable to weather changes due to the direct effects weather has on the forage resource. Therefore, the manager needs to be aware of potential drought dangers.

Effects on Forage

Variation among plant communities is primarily the result of environmental extremes such as temperature, wind, and soil moisture (Cook and Sims, 1975). Plant species have developed different strategies for coping with deficiencies in available water. Annual plants exhibit an 'escape' strategy in which they germinate early in the growing season, grow rapidly, flower, seed, and die before soil moisture is depleted. Some perennial plants exhibit an 'avoidance' strategy where deep roots, early dormancy, or stunted growth help plants endure dry periods. 'Persevering' plants withstand conditions by accumulating water within the plant as a stored reserve. However, a majority of perennials possess a 'tolerance' strategy, with which the plant changes physical characteristics to maintain essential processes (Whalley, 1973; Cook and Sims, 1975; Ludlow, 1986; Eneboe, 1996).

Drought 'tolerance' is shown as an increase in efficiency of water use. The general movement of water through the plant consists of absorption by the root system from the soil, translocation through the plant and evaporation from the leaf surface either through the cuticle or through the stomates (Whalley, 1973). Plant 'water stress' develops whenever the rate of evaporative loss from the leaves exceeds the rate of absorption through the roots (Whalley, 1973). Plants that can limit water loss to increase survivability during a period of drought (Kriedemann and Barrs, 1983).

Some adaptations of plants that aid drought tolerance are: a decrease in size of all cells; a thickened cell wall; a strongly developed palisade and mesophyll; an increase in number of stomata per unit area; and a rise in osmotic pressure. Some plants are even able to change the rate of transpiration by control of stomatal aperture (Cook and Sims, 1975). These adaptations allow the plant to continue to photosynthesize, although at a reduced rate

(Kriedemann and Barrs, 1983), and store limited amounts of carbohydrates (Julander, 1945).

Accumulation of carbohydrate reserves in plant tissue depends upon the balance between photosynthesis and respiration. Reserves are often highest at seed ripening time and decline during the dormant season. Thus, they are lowest following the start of spring growth (Figure 1). Plants decline in their ability to grow and compete with other plants if more carbohydrates from these reserves are used than are replenished by photosynthesis (White, 1973; Olson and Lacey, 1996). When photosynthetic rate falls below that of respiration, the carbohydrate reserve levels will fall. This occurs when water is limiting or when high temperatures are prevalent.

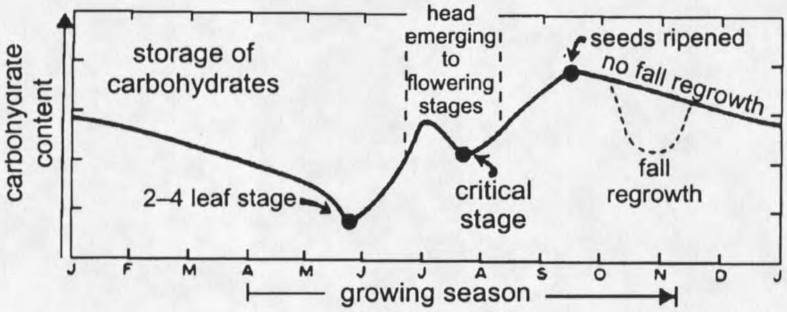


Figure 1. The pattern of carbohydrate reserves in grasses. It varies with species and environmental differences (from Olson and Lacey, 1996).

Forage production during all phases of growth and development is affected by many environmental factors such as precipitation, temperature, light, atmosphere, nutrients, and fire (Haferkamp, 1987). When environmental factors are altered beyond the range that the plant can adapt, decreases in yield and quality will follow. Growth may resume, but it will never return to the rates of unstressed plants (Hsiao, 1973; Fischer and Hagan, 1965;

Acevedo et al., 1971). The first four months of the growing season are the most critical, any serious deficiency during those months are sure to result in seriously retarded plant growth (Hurtt, 1951). Wight and Black (1979) supported Hurtt's 1951 observations of critical rain periods in early spring. In Sidney, Montana an above-average precipitation year led to low forage yields, due to a 38-day period in April and May with no rain. However, in a year of below-average precipitation, yield was high due to high precipitation in April and May.

Late in the growing season, plants change production strategies from using energy for growth and development to storing that energy in roots and becoming dormant to survive the winter. Newbauer (1985) suggested that the potential production is reduced at mid-summer due to day length induced preparation for fall and winter. Consequently, forage that is produced after a severe stress will not reach the quantity nor quality of previous yield. A severe drought year will decrease forage production of the current growing season, but can also retard grow in the following season even if the subsequent precipitation is near- or above-normal (Ellison and Woolfolk, 1937).

Defoliation also decreases plant carbohydrate levels (McIlvanie, 1942; White, 1973). Perennial grasses are most susceptible to mortality when, in a weakened condition during drought, they are grazed excessively. Continued near normal stocking pressure on drought stricken vegetation is probably the most overriding cause of range production changes (Menke, 1987).

In addition to the decrease in production directly after the drought, rangeland damaged due to previous drought and overgrazing is highly susceptible to damage in subsequent droughts. Drought studies in 1956 showed that New Mexico, Wyoming, South

Dakota, Kansas, and Colorado had areas where there were losses of 90% or more. In every location with loses of 90% or more the vegetation bore evidence of heavy use in the past (Albertson et al., 1957).

Forage Production

A decrease in precipitation will cause reduction in aboveground primary production. In Miles City, Montana, drought in 1941 showed a 20 percent decrease in forage production compared to the forage seen in 1944 (Reed and Peterson, 1961). Klipple and Costello (1960) in Colorado during drought found that during drought forage production was only 75 percent of average. Heitschmidt et al. (1999) observed a loss in total production between drought and non-drought plots of about 19 percent using rainout shelters. Albertson et al. (1957), in the Central Great Plains, discovered that where it normally required 12 acres for an animal unit, it required 30 to 50 acres following drought. Hurtt (1951) described the reduction in the forage production in Miles City during the drought of the 1930's. Drought reduced forage supply so drastically that only 36 and 23% as much unsupplemented grazing use was obtained from pastures in 1934 and 1936 as was possible in the non-drought year 1933.

Forage Quality

Forage quality is the result of species present, forage availability and composition of each species (Nelson and Moser, 1994). Forage quality is at least partially determined by energy and crude protein content, digestibility, and intake. In other words, it includes forage factors that influence animal performance. During optimal weather conditions plants grow by utilizing a high rate of photosynthesis which will fuel production of proteins and carbohydrates. Figure 2 and 3 shows the average concentration of crude protein and metabolizable energy, respectively, throughout the growing season in the Northern Great Plains (Adams and Short, 1988).

Nelson and Moser (1994) stated that water stress with minimal associated heat stress often improves forage quality due to increased leaf:stem ratio and higher digestibility of both leaf and stem fractions. Sheaffer et al. (1992) found that crude protein concentration of leaf, stem, and total forage was greater in 'droughted' forage than 'well-watered' forage. The increase in crude protein was contributed to a greater proportion of leaves and delayed maturity. Although at the onset of drought, forage quality might increase, as precipitation remains limiting the protein and carbohydrate levels will drop, and the fibrous content will increase rapidly due to the plants entering their dormancy period earlier in the growing season (Laude, 1953; Newbauer, 1985). The majority of perennial plants will become dormant much earlier in the growing season increasing the fiber content of the plants and therefore decreasing the quality of forage earlier in the growing season (Cook and Sims, 1975). Therefore, during drought, forage quality may improve in each plant, but due to decreases in forage production and early dormancy, grazing animal diets may actually be lower in nutrients than would be seen in a normal precipitation year.

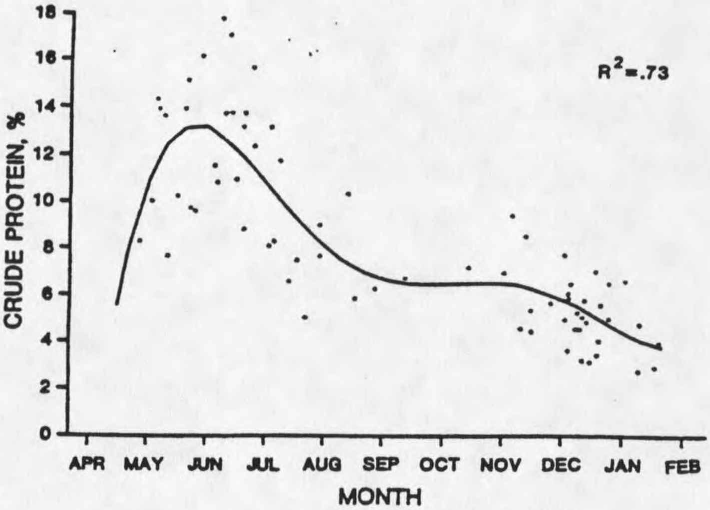


Figure 2. Concentration of crude protein in cattle diets at various times of the year on Northern Great Plains rangeland (from Adams and Short, 1988).

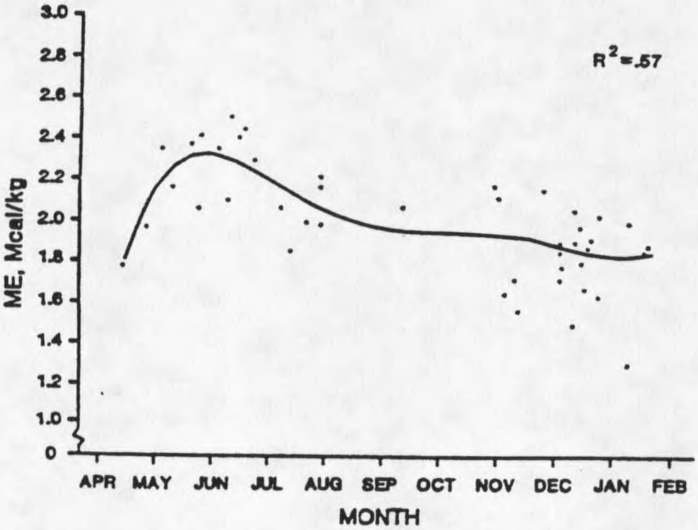


Figure 3. Concentration of metabolizable energy in cattle diets on Northern Great Plains rangeland (from Adams and Short, 1988).

Plant Vigor

Parker (1954) stated that plant vigor is indicative of short time trends in rangeland condition. Plant vigor is defined as plant strength, vitality, and life. Indicators of plant vigor are culm height, number of leaves per culm, number of inflorescences per plant, plant yield, and change in plant diameter as described by Ganskopp and Bedell (1981). One year's drought, although seriously reducing plant growth and thus available forage, may not have much effect on subsequent plant vigor seen in years following the drought (Ganskopp and Bedell, 1981). Reed and Peterson (1961) observed that two or more consecutive years of drought are necessary for an appreciable kill of plants and extended subsequent effects.

Plant Density

During severe drought, plant density, or number of plants within an area, will decrease as plant vigor decreases and death occurs. Decrease in density continues until drought is broken and the soil is again sufficiently moist to support vigorous growth of vegetation. Sarvis (1941) observed that the effects of drought on vegetation were mainly that of 'thinning the stand'. The 1930's drought reduced blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and needle-and-thread (*Stipa comata*) 90 percent in eastern Montana (Ellison and Woolfolk, 1937; Hurtt, 1951; Reed and Peterson, 1961; Whitman et al., 1943) and 50 percent in western North Dakota (Sarvis, 1941; Whitman et al., 1943). Over the four-year period 1934-1937, density of the six most important forage species fell to 8.5 percent of the 1933 level (Hurtt, 1951). Densities in the short grass communities decreased from 89 percent to 22 percent from 1934-1939 (Cook and Sims, 1975).

Plant Diversity

Plant diversity is described as the number of plant species within a specified area. If drought is severe and continued and a significant number of plants die, species that are not drought resistant will be out-competed by those that are, thereby causing a reduction in plant diversity (Whitman et al., 1943).

Basal Area

Basal area is the area of ground cover by plants of one or more species. Reduction in ground cover by desirable species constitutes land degradation due to drought (Clarkson and Lee, 1988). As forage production and density decrease due to drought, basal area decreases as well. During the 1930's drought, basal area was reduced from 26 percent in 1929 to 21 percent in 1936 in southern Alberta (Clarke et al., 1943). In Miles City, Montana during the same drought, basal area decreased from 29 percent in 1933 to 2 percent in 1937 (Hurtt, 1951; Reed and Peterson, 1961).

Effects on Livestock

One of the most important measures of animal performance is forage intake. Intake is dependent on a combination of forage, animal, and environmental factors. Forage factors include nutritional quality (Kothman, 1980), abundance (Cook and Harris, 1968), and stage of maturity (Kartehner and Campbell, 1979). Animal factors include physiological status, body size (Allison, 1985), and selection (Theurer et al., 1976; Kothman, 1980; Sindelar, 1987). Environmental factors include temperature (Adams, 1990; Fox, 1986) and hours of light (Fox, 1986). The efficiency of ruminant animals is based on the ability of the microbial population within the rumen to degrade forages. The microbial population within the ruminant stomach has the ability to degrade cellulose, hemicellulose, and lignin and transform it into usable energy for the ruminant (Van Soest, 1982). Intake is related to the amount of fiber, or structural material, found within the plant. Increases in the amount of fiber, increase the amount of time the microbes need to degrade the plant material to produce energy for the ruminant. This will decrease the passage rate of the material out of the rumen, and therefore, decrease the ability of the animal to continue to eat (Holloway et al., 1979). Thus, the cow may be unable to eat enough forage to maintain body weight. During drought, not only will forage yield be reduced, but the plants will become mature, dry and dormant (i.e. high in fiber) much earlier in the growing season.

Body Condition

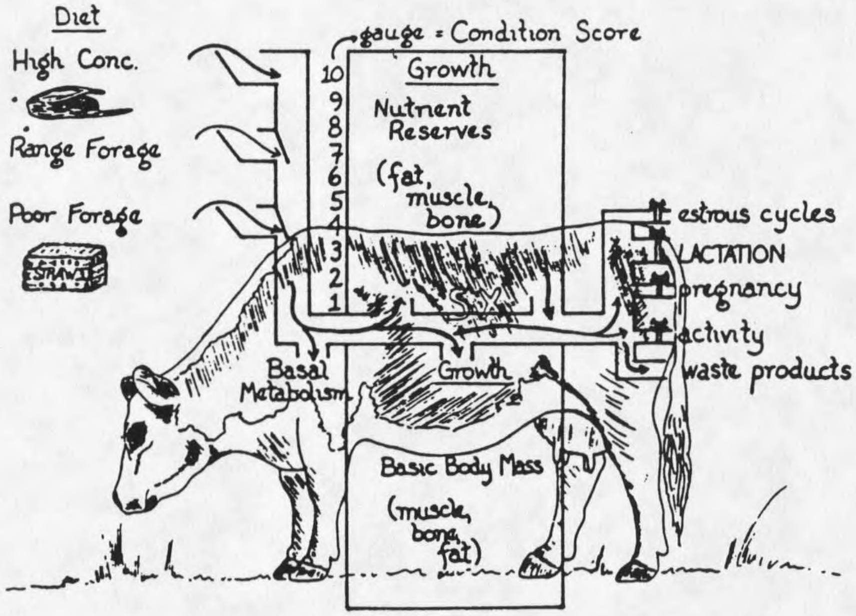
In the absence of sufficient nutrients, particularly energy, cows lose considerable weight. Hurtt (1951) and Reed and Peterson (1961) described the effects of the 1930's drought on cattle condition and weight gains in Miles City, Montana. The drought reversed the natural tendency of cattle to add weight in the summer period. Although experimental cows gained 60 to 233 pounds during summers of 1932, 1933, and 1935 they lost weight in 1934 and 1936 even with supplemental feeding. During the years 1933-1936, weight gains were only 3 to 72 pounds, where as in the normal years of 1938-1944 weight gains averaged between 120 and 180 pounds. By 1936, the cost of supplemental feeding just to impede the results of starvation was so high that the Miles City Research Station sold all cattle remaining in the study.

Reproduction

Drought can reduce calf crop numbers in the following year rather than the current year. Cows that lose body condition during drought may fail to come into estrus in the breeding season, decreasing the number of calves produced. The drought in the 1930's caused a 33 percent loss in total calf production and the average weight loss in the drought years was 99 lbs/calf due to a reduction in percent calves weaned and decreases in weight per calf (Hurtt, 1951).

A concern for producers is reproductive efficiency, or total pounds of calf weaned per cow exposed to a bull (Dzuik and Bellows, 1983). Reduced reproductive performance increases annual production costs per cow exposed (Wittum et al., 1990), where the greatest loss is failure of cows to become pregnant (Wiltbank et al., 1961). The postpartum interval (**PPI**, time between calving and first estrus that is accompanied by ovulation) will determine whether or not the individual will calve the following year. A cow must conceive by 80 days postpartum to have a 365-day calving interval (Dunn and Kaltenbach, 1980). Factors that substantially influence PPI are level of nutrition (Dunn and Kaltenbach, 1980; Richards et al., 1986; Sasser, et al., 1988; Selk et al., 1988; Randel, 1990; Houghton et al., 1990) and cow condition prior to parturition (Dunn and Kaltenbach, 1980; Richards et al., 1986; Selk et al., 1988; Houghton et al., 1990).

The normal partitioning of nutrients to various body functions is illustrated in Figure 4 (Adams and Short, 1988). Nutrients are not allotted to reproduction until requirements for maintenance, growth, and lactation are met. In drought conditions, nutrient intake can be severely decreased causing many animals to decrease body conditions to such an extent that body fat reserves are not sufficient for cows to resume estrous cycles (Webster, 1973; Dunn



The approximate order of priority for partitioning of nutrients:

1. Basal Metabolism
2. Activity
3. Growth
4. Basic energy reserves
5. Pregnancy
6. Lactation
7. Additional energy reserves
8. Estrous cycles and initiation of pregnancy
9. Excess reserves

Figure 4. Partitioning of nutrients in a cow with nutrient intake varying in quantity and quality (from Adams and Short, 1988).

and Kaltenbach, 1980; Smith and Foran, 1992; Keisler et al., 1999). Reed and Peterson (1961) observed this in Miles City, Montana during the 1933-1936 drought where cows produced 54.9 pounds less calf weaning weight. This is equivalent of losing a 450 pound weaned calf a year for every 8.2 cows.

Drought conditions can delay puberty of replacement heifers by restricting the amount of weight gained. The rule of thumb is that each heifer should achieve 65% of her mature weight by 14-16 months of age. Under-nourished prepuberal animals will not enter puberty until they are well fed (Amstalden et al., 2000). Heifers bred to calve at two years produce more calves in a lifetime with higher average weaning weights, than those bred to calve first at three years (Lesmeister et al., 1973). In addition, high monthly maintenance costs make it necessary to get heifers into production as early as possible (Thomas et al., 1990). If the drought is prolonged and severe undernourishment continues, heifers may be stunted causing reduced reproductive performance during adult life (Webster, 1973).

The PPI for first-calf heifers is generally longer than for mature cows (Wiltbank, 1961; Bellows and Short, 1978; Triplett et al., 1995) thus contributing to lower pregnancy rates for heifers (Lalman et al., 1997). First-calf heifers are still growing, nursing a calf, and are expected to rebreed (Bell et al., 1990). The PPI is greatest when heifers are in thin condition (Reichards et al., 1989; Houghton et al., 1990; Spitzer et al., 1995). Body condition of first-calf beef cows at calving is a reliable indicator of subsequent reproduction (DeRouen et al., 1994).

Calf Crop

Calves become ruminally active at 45 to 60 days and are selective grazers, selecting a diet higher in protein and energy than their dams (Ansotegui, 1986). As discussed previously, forage quality and quantity decreases as drought continues. Calves may not be able to utilize available forage due to the decrease in nutritional value and palatability (Brownson, 1976; Adams and Short, 1988). This could result in an increased dependence on milk provided by the dam (Short et al., 1996). Stress to the cow can decrease the ability to produce enough milk to allow calves to reach desired weaning weights. The end result will be lighter calves than seen during a normal precipitation year. Reed and Peterson (1961) described the trends in calf weights during the drought of 1933-1936. At weaning, calf weight gains were almost half of normal, while yearling heifers were 118 pounds underweight and yearling steers 135 pounds underweight. At Mandan, North Dakota, yearling steer gains over a 16-year period followed closely to the climatic conditions and the quantity of forage produced. During the 16-year study yearling steers gained about 1.7 pounds per day during dry years and more than 2.0 pounds per day during the more favorable years (Lorenz, 1974).

Effects on Profitability

Profitability for the cow-calf enterprise is affected by many interacting variables. A simplified profitability formula (Taylor and Field, 1999) is as follows:

$$\text{Profit [Loss]} = \text{Income} - \text{Costs}$$

This can be written specifically for ranching operations as:

$$\text{Profit [Loss]} = (\text{Pounds} \times \text{Price}) - \text{Costs}$$

To increase profit (or minimize loss), producers focus on three areas: (1) increase pounds, (2) increase price, and (3) decrease cost. Producers generally do not have the ability to significantly change the price received for their product. Therefore, any change in profit, or loss, comes from the interaction between amount of pounds produced and the cost of producing those pounds. Feed costs (including purchased feed, harvested feed, and grazed forage) comprise 54 to 75% of the annual cow costs in many cow-calf operations (Taylor, 1984; Taylor and Field, 1999). Table 1 shows the relationship between annual cow cost and the breakeven price ($/cwt.). As the annual costs per cow increase and pounds of weaned calf is held constant, the breakeven price increases dramatically.

Table 1. Effect of Changing Annual Cow Cost on Breakeven Prices (assumes 80% calf crop and 500 lb. Weaning weights) (From Taylor and Field, 1999)

Annual Cow Cost	Breakeven Price ($/cwt)
$450	$1.12
400	1.00
350	0.88
300	0.75
250	0.62
200	0.50

Drought can affect profit. A reduction in precipitation will produce a reduction in forage yield decreasing the carrying capacity of the rangeland. Managers are forced to decrease the pressure on the forage, or be faced with a damaged forage resource. Weight changes can affect profitability directly especially when feed must be purchased to prevent or counteract weight losses (Hart, 1987). Hurtt (1951) described the effect of increased costs for feed and increased demand for supplemental feed of the cows during the drought year of 1934. Hay costs per ton jumped 52 percent from the 1932 level and as a result, hay cost per cow increased by 94 percent.

Monetary losses to farmers during drought come in the form of forgone production from depressed biological rates, damage to rangelands, low yields of range crops, increased cost of hauling water, lack of reserves, increased feed costs, depleted cash reserves, and the pressing need for cash income (Anderson and Hardaker, 1973; Kulshreshtha, 1989; Hanselka and Landers, 1993).

CHAPTER THREE

DROUGHT MANAGEMENT

Drought management as practiced by good managers who are concerned with landscape integrity, animal production and financial returns, will be a mix of long-term strategy and short-term tactics (Foran and Smith, 1991). Planning for the correct stocking rate is one of the most effective ways of maintaining healthy rangeland before drought strikes.

The crux of the problem lies in balancing forage supply to the animal's nutrient demand. Forage quantities and qualities fluctuate widely over time due to plant phenology and physiology, weather conditions, and season of the year. At the same time, animal demands change with changing animal age and physiological state. How long the forage inventory will last will be determined by season (probability of useful precipitation) and animal demand. This process allows one to reconcile stocking rates with carrying capacity.

Most tactical responses to emerging drought are aimed at reducing grazing pressure on the stressed forage resource. This can be done by acquiring more forage (leasing pasture, supplementation), reducing requirements of animals (early weaning calves), or reducing stocking rate (culling, early weaning calves).

Early Weaning Calves

Early weaning can be a useful tool during conditions when forage for the cow herd is inadequate, cows are too thin to breed, or other conditions in which the amount of purchased feed required to maintain both cow and calf can be more efficiently fed directly to the calf (Lusby et al., 1990). In typical beef cattle production systems, calves are weaned at approximately 205 d of age (Fluharty et al., 2000). However, declining milk production after the third month of lactation (Neville, 1962; Robison et al., 1978; Bartle et al., 1984) and reduced productivity of pastures (Burns et al., 1983) limits calves energy intake and growth. Early weaning (Peterson et al., 1987; Myers et al., 1999a) has shown promise as a means of increasing calf growth.

Removing the calf will obviously reduce the quantity and the quality of forage needed to maintain the cow herd. Lactation roughly doubles the daily energy and protein requirements for a typical beef cow (NRC, 1996). Early weaning eliminates the nutrient needs for milk production and therefore, decreases intake needed to maintain cows. Peterson et al. (1987) reported that early-weaned cow-calf pairs were 43% more efficient in converting total digestible nutrients into calf gain than were normal-weaned cow-calf pairs. This reduction in forage demand will increase carrying capacity of the stressed pasture and allow the forage base to feed the herd for a longer period of time.

The fetus a cow is carrying should be of as much concern as the nursing calf. Stress can result in light, weak calves a birth and dams that have reduced colostrum, especially in drought years. From the standpoint of the cow, the advantage of early weaning during drought periods is usually reflected in less body condition loss (Moore and Camps da Rocha, 1983; Myers et al., 1999a; Story et al., 2000) and improved conception rates (Lusby et al.,1981; Herbel et al., 1984). Myers et al. (1999b) found that when calves were weaned at 90 days cow pregnancy rate increased by 12 percent and cow condition increased as weaning age decreased.

Some concerns of early weaning relate to weaning small calves. In most cases, early weaning will mean the calves have to be fed in dry lot, therefore adding feed and overhead costs that would not be incurred on later-weaned calves. If calves are fed correctly and proper management is observed these early-weaned calves will perform as well as or better than a normal weaned calf at six to seven months. Early weaned calves have a higher average daily gain (Barker-Neef et al., 2001; Fluharty, et al., 2000; Myers et al., 1999b), increased feed efficiency (Myers et al., 1999a,b; Barker-Neef et al., 2001), lower cost of gain (Story et al., 2000; Barker-Neef et al., 2001), similar or better carcass characteristics (Story et al., 2000; Myers et al., 1999b; Barker-Neef et al., 2001), but lower carcass weights (Story et al., 2000; Barker-Neef et al., 2001) than calves raised on dams during normal production years

Although early weaning is certainly not advocated for all producers all of the time, it can provide an attractive alternative in certain situations such as drought, when large amounts of purchased forage would be necessary to maintain a cow herd through to normal weaning time or when cows are already too thin to rebreed.

Culling Strategies

Reductions in stocking rate will benefit range plants by reducing stress and will also provide more forage for remaining cattle. When stocking rates are reduced in accordance with production, only small effects on weaning weight may be noted. Because heavy grazing intensifies drought effects, decreasing cow numbers minimize damage to pasture (Clarkson and Lee, 1988). If stocking rate is not reduced, supplemental feeding is necessary to maintain herd productivity and alleviate grazing pressure.

Cull cow sales comprise 15-30% of cow-calf enterprise gross revenue (Little et al., 2002). Culling would normally occur at weaning when calves are 6-7 months of age. For spring calving animals this would occur in late October and early November. These animals are often in poor body condition, which results from the combined effect of lactation and deteriorating forage quality reducing possible revenue (Little et al., 2002). Since both wet and dry cows gain very little at best and often start losing weight early in drought years, holding cattle that have been designated for sale only invites increased loses. Drought will bring a high supply of livestock coming to market depressing prices. Reduced stock numbers early in a drought may take advantage of current prices before they begin to decline (Robinson, 1982).

The rancher is especially interested in saving as much of his breeding stock as possible, but these animals are consuming valuable resource and unnecessarily reducing the available forage for the remaining herd. Therefore, careful culling of animals that are borderline and old that probably would be culled at or near the end of drought due to old age or other reasons, would make certain that the best breeding cows get all of the available forage and hay to maintain their vigor (Hurtt, 1951).

Leasing Pasture

It should be pointed out that extreme drought conditions, or droughts of long duration, seldom cover more than a particular region of the western USA range area. Therefore, the entire livestock industry of the west rarely suffers a poor production year, and thus, relief can be received by an interchange of grazing agreements among grazing areas (Cook and Sims, 1975).

Acquiring more forage would enable a producer to maintain the traditional herd size without sacrificing cow condition or calf performance. Depending on how severe and widespread the drought, pasture leased could be hard to find, expensive, and considerable distance from the operator. Livestock transportation costs are high and livestock performance is often depressed from the stress of hauling and adjustment to a new area (Holechek, 1993).

CHAPTER FOUR

COMPUTER MODELING

Modeling and systems analysis attempt to integrate, interpret, and apply scientific information from several disciplines in a way that the information can be directly applied to decision making (Tess and Kolstad, 2000a). Spedding (1988) defined modeling as an "abstraction and simplification of the real world, specified so as to capture the principal interactions and behaviour of the system under study and capable of experimental manipulation in order to project the consequence of changes in the determinants of the system's behaviour." Spedding further delineated the definition of modeling by stating that "practical application requires (a) that relationships are quantified and (b) that they adequately reflect the essential complexity of real-life relationships."

Computers are now often used to develop and use models, which are composed of complex mathematical equations. It is advantageous to use the computer due to the speed at which calculations can be made, its capability for handling many equations and concepts systematically, and its ability to re-evaluate these equations over many replications in relatively short periods of time (Davis, 1992). There are several types of computer models that are useful in understanding biological processes including statistical regression models, and computer simulation models that include a systems approach to modeling, such as ecosystem level range models and beef production system models.

Predicting Drought

National methods of predicting drought use global weather patterns to determine significant deviations in precipitation for regions. The Palmer Drought Severity Index (PDSI) developed by Palmer (1965), is the major index used in the United States. Models that describe the intensity of a drought are often called indices. The PDSI is often used to trigger U. S. drought relief programs (Willeke et al., 1994). This is generally a good measure of intensity of drought, but can only be used in homogenous topographic regions. Therefore, areas of frequent climatic change and variable topography have weak estimations of drought at best (Alley, 1984; Karl and Knight, 1985).

A derivative of the PDSI is the Crop Moisture Index (CMI) developed by Palmer, (1968). This model uses a meteorological approach to monitor week-to-week crop conditions. The CMI is closer to measuring agricultural drought within a region, but it starts at zero each growing season not taking into account precipitation during the winter, and therefore cannot be used for predicting long-term drought (Hayes, 2002). Again the CMI can only determine the extent of drought within homogenous regions which limit use.

The National Drought Mitigation Center is using a newer index, the Standardized Precipitation Index (SPI) developed by McKee et al. (1993), to monitor moisture supply conditions. Distinguishing traits of this index are that it identifies emerging droughts months sooner than the Palmer Index. Both the PDSI and SPI are measuring meteorological drought, the occurrence or absence of rain during the calendar year.

The National Oceanic and Atmospheric Administration (NOAA), the National Drought Mitigation Center (NDMC) at the University of Nebraska, and the United States Department of Agriculture (USDA) work together with the Climate Prediction Center (CPC) to administer the United States Drought Monitor (Drought Monitor, 2002). This program produces a weekly report on a map of the United States describing drought intensity. The U.S. Drought Monitor uses a complex set of models and equations to forecast the strength of drought affecting areas and regions. This index is useful in defining emerging drought in large regions.

These models are useful for defining the weather trends for an area, but have limited usefulness for the producer. Soil types, slope of the land, types of plants, etc. are factors that can significantly effect forage production. These factors are highly variable and can change forage yield from pasture to pasture. Site-specific models are needed to respond to that variability. Models that can be used for a single ranch are aimed at forecasting forage production for that growing season.

Statistical Regression Models

Many researchers have used simple, single equation regression models to define significant predictors of forage production. Range productivity models serve to estimate production and show relationships between variables (Cannon and Nielsen, 1984). Regression models might be able to give the most realistic estimate of the effect of weather modification on forage production (Perry, 1976). The vast majority of the research done has shown that some measure of precipitation is one of the most important factors in forage growth. The effect of timing, frequency, and the amount of rainfall from single storms are important in water use efficiency (Wight and Black, 1979), nutritive levels of grass (Rogler and Haas, 1947), community composition (Albertson and Tomanek, 1965), and phenological events (Sundberg, 1974; Beatley, 1974). Table 2 shows a comprehensive list of the major research done using statistical regression models to predict forage production in the past 70 years.

Correlation coefficients and regression equations define herbage yield dependence upon precipitation, but do not provide a suitable technique for application to other areas (Sneva and Hyder, 1962b). Sneva and Hyder (1962b) described that if the actual yields and precipitation amounts were expressed in proportion to longtime expectations, an herbage-response line representative of many different areas could be computed. In a single growing season herbage growth depends largely on the amount of precipitation received immediately before and during the growing season. Therefore, crop-year precipitation amounts are not the same as calendar year amounts. The crop-year must begin at the close of a previous growing season and terminate at the close of a current growing season. Yield indices in semi-arid closed communities of native or well-adapted introduced species fluctuate with precipitation indices in a fairly uniform and predictable manner.

Sneva and Hyder (1962b) estimated herbage production in eastern Oregon, Utah, and Idaho using median values, instead of mean values, for predictors. Median values are less responsive to extreme precipitation years. They calculated long-term median precipitation, median forage yield, and actual precipitation and yield amounts expressed in percent of the median precipitation and median yield. They found correlation coefficients of .98 to .80 for between forage production and median values of precipitation.

Sneva and Hyder (1962a) reported that on semiarid ranges 75 to 90% of the yield fluctuations among years can be attributed to variation in precipitation amounts. Distribution of precipitation, effectiveness of precipitation, temperature, and quality of the preceding crop-year together accounted for less than 25% of the variation in yield. They stated that they would expect in approximately two-thirds of the years the estimated yield would be within 18% of the true yield.

Some of the listed studies in Table 2 found a critical time where the forecast could be made with some accuracy. Smoliak (1956) found that the sum of May and June precipitation, similar to that of the seasonal precipitation, could be used to predict forage production by July 1st in southern Alberta ($P < 0.5$). Sneva (1982) found for eastern Oregon that September through June precipitation was highly significant as a predictor, but forage production could be forecasted as early as April 1st with a high degree of accuracy. Using the median method described by Sneva and Hyder (1962a) several researchers found dates where forage yield could be forecasted for the growing season. Sneva and Hyder (1962 a,b) stated that a forecast could be made by July 1st, or the end of the crop-year. Hanson et al. (1983) found that yield could be forecasted by April 1st using the same method in southeastern Idaho.

Soil moisture may be the one best predictors of forage yield because it is a measure of the amount of water that is directly available to the plants. It takes into account distribution of precipitation, runoff, and evaporation (high temperature). Available water-holding capacity, texture, and bulk density are among soil properties correlated with productivity (Cannon and Nielsen, 1984). Soil moisture is about equivalent to seasonal precipitation for estimating range forage yields, but tends to be more site-specific (Wight, 1978). The relationship between precipitation and soil moisture recharge, especially overwinter recharge, is an indirect method in which precipitation can be useful in predicting forage production (Wight, 1978). The water movement through soil is influenced by temperature and drought is usually accompanied by extreme heat. Increases in temperature decrease the water-holding capacity of soil and decreases in temperature increase the capacity in soil (Daubenmire, 1957).

Yield of native range in the northern Great Plains generally increases as available water increases. However, as water becomes more plentiful, other factors limit yield. For a given plant community, addition of water beyond a certain level has limited value for increasing yield (Wight and Black, 1979). Another factor affecting the linear relationship between precipitation and forage production is the limiting effect of nutrient deficiencies, as soil moisture becomes non-limiting (Perry, 1976; Wight, 1978). Rather than being a linear relationship, forage yield as a function of water availability may asymptotically approach some maximum determined by available N (Perry, 1976). Nitrogen was the major limiting nutrient, and forage yield generally increased as N rates increased (Wight and Black, 1979). Wight and Black (1979) found that eliminating deficiencies in soil nutrients, N and P, increased forage production of an average of 114% in an average precipitation year (32% in a "dry" year and 218% in a "wet" year). Unfertilized plots produced an average of 2.60 kg/ha for each 1 mm of precipitation received as compared to 5.81 kg/ha on fertilized plots.

Using simple statistical models can be useful in finding relationships among factors in a small area, but more complicated interrelationships between environmental factors and forage production may be better explained by more complex ecosystem level range models.

Table 2. Publications predicting forage yield from precipitation.

Author(s)	Year	Location	Predictor[a]	r[b]	Decision Date[c]	Comments
Craddock & Forsling	1938	Southern Idaho	Prev Winter & Current Spring Precip	0.94		
Sarvis	1941	North Dakota	April – June Precipitation			
Clarke et al.	1943	Southern Alberta	Precipitation/evaporation Ratio			
Rogler & Haas	1947	Mandan, ND	Soil Moisture, Fall & Spring Precip	0.73*		
			April – July Precipitation	0.76*		
Reynold	1954	Desert Grassland	Annual Precipitation			
Smoliak	1956	Alberta	May + June Precipitation	0.86*	July 1st	
			Seasonal Precipitation	0.85*	July 1st	
Stitt	1958	Mocassin, MT	April – May Precipitation	*		Regressions on individual species
Abel et al.	1962	Northern Great Plains	Mar-Jun Precip + May and Jun Temp			
Sneva & Hyder	1962a,b	Eastern Oregon	Current Median Precip + Current Forage	0.98 to 0.80	July 1st	Uses Median Method
Dahl	1963	Akron, CO	Previous 2 yrs. Precipitation	0.89*		
Rauzi	1964	Laramie, WY	May + June Precipitation	0.68		
			April – August Precipitation	0.75		
Currie & Peterson	1966	Colorado Springs, CO	April precipitation	0.94		Grazed in spring
			May + June Precipitation	0.97		Grazed in fall
Rosenzweig	1968	World	Actual Evapotranspiration			
Hulett & Tomanek	1969	Western Kansas	Seasonal Precipitation			
Hausle	1972	Kansas	April – Sept. Precipitation			
Ballard	1973	Miles City, MT	June – October Precipitation	0.60		Individual grass species

[a] Varialbles used to predict yearly forage production

[b] Correlation found from the selected variables

[c] Date at which forage production can be predicted

*P-value < 0.05 **P-value < 0.01

Table 2 (con't). Publications predicting forage yield from precipitation.

Author(s)	Year	Location	Predictor[a]	r[b]	Decision Date[c]	Comments
Shiflet & Dietz	1974	Kansas	April – Sept. Precipitation	0.78*		
Duncan & Woodmansee	1975	CA	April Precipitation	0.41*		
Sneva	1977	Southeastern OR	July – May Precipitation	0.76**		Seeded Crested Wheatgrass
Roundy et al.	1979	Northern Nevada	Previous Winter and Current Spring			Also predicts soil moisture and length of growing season.
Johnson	1981	South Dakota	Sept. - June Precipitation			
Sneva	1982	Eastern OR	Sept. – June Precipitation	0.92**	April 1st	
Olson	1982	Miles City, MT	Plant Year Precipitation	0.81		
Hanson et al.	1982	Alberta	Previous Yr. Forage Yield	0.32*		
Hanson et al.	1983	Southeastern ID	Sept. – April Precipitation	0.76 to 0.93	April 1st	Uses Median Method (Sneva & Hyder, 1962)
Cannon & Nelson	1984	MT, WY, ND, Alberta	Depth of Soil and Moisture	0.85*		
Wisiol	1984	World	Past Yr Forage Yield + Current Precip			Prev published equations/over-estimates
White	1985	Dickenson, ND Sidney, Mocassin, MT Saskachewan	April + May Precipitation	0.63 to 0.77**		
Smoliak	1986	Alberta	April – July Precipitation Annual Precipitation Previous Yr. + July Precipitation	0.58* 0.74* 0.74*	Aug. 1st Aug. 1st Aug. 1st	
Sala	1988	Great Plains	Annual Precipitation	0.95*		Predicts ANPP for MLRA
Milchunas et al.	1994	Northcentral CO	Cool Season Precipitation			Grazing Systems

[a] Varialbles used to predict yearly forage production
[b] Correlation found from the selected variables
[c] Date at which forage production can be predicted
**P*-value < 0.05 ***P*-value < 0.01

Computer Simulation Models

Researchers often desire to seek information about large, complex systems that under conventional research methods would be expensive and time consuming to collect. It can then be possible to use a simulation model to depict these complex systems using interacting mathematical equations.

Ecosystem Level Range Models

Ecosystem level simulation models are designed to take into account the distribution of precipitation over growing season and nutrient cycling as well as using temperature, soil and vegetation characteristics of the site in question. These simulation models use interacting equations to estimate various components of forage growth allowing more than one factor to influence yield. The differential impacts of factors are taken into account when model is built.

There are several ecosystem level models available for use to predict forage production. The history and development of several major ecosystem level range models are described in Table 3. The SPUR (Simulation of Production and Utilization of Rangelands) model developed by Wight and Skiles (1987) and modified by Hanson et al. (1992), Carlson and Thurow (1992), Foy (1993), Foy et al. (1999), and Pierson et al. (2001), is a complex ecosystem level model that simulates plant growth, animal production, and economic results. This model is mostly used only for research purposes mainly due to complexity of parameterization.

Table 3. History and development of several major ecosystem level range simulation models.

Model	Researcher	Year	Function
ELM (Ecosystem Level Model)	Innis	1978	Simulates biomass dynamics in a variety of grassland types and the response of the system to fertilization, irrigation, and cattle grazing
SPUR (Simulation of Production and Utilization of Rangelands)	Wight and Skiles	1987	SPUR User Guide. Ecosystem level model designed to simulate the complex climate, hydrology, plant, and animal interactions on rangelands. Worked well on shortgrass prairie, but didn't work on sites with multiple growing seasons and both warm and cool season grasses.
	Mac Neil et al.	1985	Sensitivity analysis
SPUR2	Hanson et al.	1992	SPUR2 User Guide. Modified SPUR. Upgraded plant-animal interface, provided greater flexibility for grazing systems, added a cow-calf beef model, and improved user interface.
	Stout et al.	1990	
	Baker et al.	1992a	
	Baker et al.	1992b	FORAGE model
	Baker et al.	1993	
	Eckert et al.	1993	
	Hanson et al.	1993	
SPUR-91	Carlson et al.	1995	SPUR91 User Guide
	Carlson and Thurow	1992	Revision of original SPUR. Improved the hydrology-plant intercommunication.
	Carlson and Thurow	1996	Model tested and was reliably used to predict general trends rather than absolute values of management responses (Hanson et al., 1999).
SPUR-CENTURY	Foy	1993	Upgraded soil carbon and nitrogen cycling processes by adding applicable submodels from the CENTURY model (Parton et al., 1992).
SPUR 2.4	Foy et al.	1999	Integrated all previous versions of SPUR and there is now a potential for incorporating the assessment of various management strategies and practices in limited areas.
SPUR 2000	Pierson et al.	2001	Upgrade incorporates a process-based hydrology component and addresses the complexities of overland flow. It adds an erosion prediction model WEPP (Flanagan et al., 1995).
RAPPS (Rangeland Plant Profiles)	Dougherty et al.	1994	Calculates biomass production per unit area by plant part, digestibility, forage quality, plant dimensions and morphology, and timing of phenological events.

Table 3 (con't). History and development of several major ecosystem level range simulation models.

Model	Researcher	Year	Function
	Wight and Hanks	1981	Water-balance, climate model for range herbage production. It predicted annual herbage production for range sites within 10% of field measured yields.
ERHYM (Ekalaka Range Hydrology Yield Model)	Wight and Neff	1983	Provides daily simulation of runoff, soil water, evaporation, transpiration, and soil water routing. Herbage yield is computed annually at peak standing crop. Used Smith and Williams, 1980.
	Wight et al.	1984	Used model to relate soil water and climatic parameters to plant growth. Found that two-thirds of the field measured yields were within one standard deviation of forecasted yields for the April, May and June forecasts using 55 years of weather records and 12 years of actual yield and soil water data.
ERHYM-II	Wight	1987	Upgraded version of ERHYM
	Wight and Hanson	1991	Compared long-term historical and stochastically generated weather records in terms of their statistical attributes and effects on herbage yield and runoff forecasts calculated from model simulations. Yield forecasts were similar using either historical or synthetic weather records.
RANGETEK (1.0)	Wight	1991	Slightly modified version of ERHYM-II
PHYGROW	PHYGROW, 2002		Hydrologic based plant growth simulation model. Developed and maintained at Texas A&M University
PHYGROW 1		1993	Used formulas from EPIC, SPUR, and CREAMS models for soil hydrology and plant growth model. Didn't match soil moisture well with rainfall conditions.
PHYGROW 1.2		1994	WEPP equations take the place of EPIC equations.
PHYGROW 2		1996	More than one functional group can be modeled on the same site, more than four layers of soil can be modeled hydrologically, and time periods can be for more than one year.
PHYGROW 3		1999	Implements vegetation consumption (grazers, fire, and insects) as driven by stocking rate rules. It is now a multi-platform java program that can utilized on the internet.

Another model, PHYGROW, developed at Texas A & M University has been made available to the public to use on the internet (PHYGROW, 2002). This model uses soil characteristics, plant community characteristics, and weather data for a particular location to predict forage production.

A more user friendly model, RANGETEK, developed by Wight and Hanks (1981) and modified by Wight and Neff (1983), Wight (1987), and Wight (1991), uses a water-balance, climate approach to simulate forage production. Rangetek is a modified version of the Ekalaka Rangeland Hydrology and Yield Model (ERHYM) developed by Wight and Hanks 1981, is a general ecosystem level model used as a decision support tool. It is a climate/water-balance model, which provides daily simulation of soil water evaporation, transpiration, runoff, and soil water routing for individual range sites. It can utilize real-time climate data to simulate ongoing processes, or to utilize long-term weather records to simulate runoff and herbage production under a range of climatic conditions and management practices.

The original model was a modified crop model (Hanks, 1974; Rasmussen and Hanks, 1978). Yield is determined as a function of actual to potential transpiration ratio annually at peak standing crop. Predicted annual herbage production for range sites were within 10 % of field measured yields (Wight and Hanks, 1981). In 1983, Wight and Neff provided the ERHYM User Guide that added calculations for infiltration and runoff from daily rainfall (Smith and Williams, 1980). The model found two-thirds of field measured yields were within one standard deviation of forecasted yield for the April, May, and June forecasts using

55 years of weather records and 12 years of actual yield and soil water data (Wight et al., 1984). The ERHYM-II (Wight, 1987), an upgraded version of ERHYM, added routines for the simulation of soil temperature (specifically the EPIC soil temperature routine), maximum and minimum air temperature, and solar radiation plus a few minor modifications. Wight and Hanson (1991) compared long-term historical and stochastically generated weather records in terms of their statistical attributes and effects on herbage yield and runoff forecasts calculated from model simulations and found that yield forecasts were similar using either historical or synthetic weather records. In 1991, RANGETEK, a modified version of ERHYM-II, was made available to the public. Wight added the Ritchie technique for partitioning evapotranspiration into evaporation and transpiration based on leaf area index and a mulch factor calculated from percent bare ground (Renard et al., 1987, Ritchie, 1972, Ritchie et al. 1976).

Beef Production System Models

In addition to plant growth models, many researchers have been working on developing range beef production models that are dynamic in nature to calculate livestock performance and economic returns as a result of differing management decisions. A history and development of beef production system simulation models is given in great detail in Kolstad (1993), Julien (1997), Fuller (1998), and Reisenauer (2001).

The Texas A & M Model developed by Sanders and Cartwright (1979a,b) and modified by Notter et al. (1979a,b,c), Kahn and Spedding (1983;1984), Kahn and Lehrer

(1984), and Bourdon and Brinks (1987a,b,c) is probably most widely used. This model has been used to evaluate management decisions on different forage types, carrying capacities, cow size, milk production, weaning strategies, life-cycle efficiency, and how biology and economics interact (Angirasa, 1985; Doren et al., 1985; Stokes et al., 1986; Bourdon and Brinks, 1987a,b,c).

The Montana State University range beef production model developed by Tess and Kolstad (2000a,b) was designed to simulate "1) the performance of diverse genetic types in response to changing forage quality and management strategies, accounting for dynamic interactions among cattle genotype, forage quality, and physiological state, and 2) the economic performance of cow-calf production systems in response to alternate breeding and management systems." Forage intake, energy and protein metabolism, growth, reproduction, lactation, and changes in chemical body composition are simulated for individual animals over complete life cycles. Animal performance, management decisions and land resource expenses are tabulated. Several biological and economic measures can be computed, including ratios of inputs (e.g. DM, CP, ME, and dollars) to outputs (e.g. weight, lean, breakeven prices, and annual gross margin per cow or ranch. Uses for the model include evaluation of system responses to changes in breeding strategies and management in range production and marketing systems.

To illustrate the model's performance, experiments were simulated to demonstrate life-cycle weight and body condition changes for different genotypes raised in a northern range environment; responses in forage intake and weight changes in forage quality, protein supplementation, and cow physiological state; responses in reproduction, weight, body condition, and calf growth differences in pre- and postpartum nutrition; and differences in enterprise efficiency and profit for different genotypes and mating systems (Tess and Kolstad, 2000b). Kolstad (1993) used this model to measure economic performance of different strains of composite cattle in different rotational grazing systems. Julien and Tess (2002) analyzed different management practices for increased profitability. Torstenson et al. (2002) used the MSU model coupled with an elk model to determine economic costs of elk utilization of forage growth. Reisenauer (2001) used the model to evaluate different seasons of calving in the Northern Great Plains.

CHAPTER FIVE

OBJECTIVES

The objectives for this research were to identify a practical predictor of drought-induced forage yield reduction, and to evaluate alternative drought management strategies for their effects on profitability based on early detection of drought.

Thirty years of climate records from Miles City, Montana and Lethbridge, Alberta were utilized as inputs for an ecosystem level range simulation model to produce forage production data. Simulated results were compared to forage data from the Fort Keogh Livestock and Range Research Laboratory (LARRL) and Manyberries Station, to evaluate the validity of the model. Regression techniques were used to identify seasonal precipitation patterns that predicted large drops in forage yield. The analysis of the relationship between precipitation and forage production was done to define a critical time where current growing season production could be forecasted.

A bioeconomic computer simulation model was used to determine the effects of manipulating management strategies on enterprise profitability during drought. Treatments were arranged in a 4^2 factorial arrangement where management, level of drought, purchased hay cost, and forage quality were evaluated for those effects on system performance. A second bioeconomic computer model was used to simulate drylot performance for early-weaned calves. Outputs from the two models were combined and treatments were evaluated based on feed costs, average calf weaning weight, ranch gross margin, and cumulative gross margin.

CHAPTER SIX

OBJECTIVE ONE
PREDICTOR OF FORAGE PRODUCTION
MATERIALS AND METHODS

Drought is an inevitable phenomenon in the Northern Great Plains. Drought affects forage production (Reed and Peterson, 1961; Heitschmidt et al., 1999), forage quality (Sheaffer et al., 1992), and diet quality of grazing animals (Laude, 1953; Cook and Sims, 1975). An important question for producers is when should they make changes in management in response to emerging drought. Therefore, our objective was to identify a practical predictor of forage production early in the growing season to predict emerging drought.

Our first attempt used a small forage dataset from various studies done at Fort Keogh. The statistical analysis showed that the dataset was too small to separate the effects of precipitation and temperature on forage production. Therefore, we employed an ecosystem level range model to produce yearly forage data based on historical precipitation and temperature records. The model was parameterized to represent rangeland in the southeastern plains of Montana and the southeastern plains of Alberta. These results were coupled with historical weather data to determine which measurements of rainfall and temperature were the most practical predictors for the forage production.

Rangetek (ERHYM-II) Model

The Ekalaka Rangeland Hydrology and Yield Model developed by Wight and Hanks (1981) and modified by Wight and Neff (1983), is a general ecosystem level model used as a decision support tool. It is a climate/water-balance model, which provides daily simulation of soil water evaporation, transpiration, runoff, and soil water routing for individual range sites. It can utilize real-time climate data to simulate ongoing processes, or to utilize long-term weather records to simulate runoff and herbage production under a range of climatic conditions and management practices (Wight, 1987). This model was used because it is relatively simple, requiring only four driving variables, as well as state variables, including soil, plant, and runoff parameters (Johnson, 1985). Driving variables are daily precipitation (inches), minimum and maximum air temperatures (°F), and solar radiation, which can be simulated by the model.

Plant variables required by the model include percent graminoids, percent bare ground, leaf area index, date of start of growing season, date of peak standing crop, date of end of growing season, and a relative growth curve. Soil inputs include number of soil layers, texture, thickness, percent organic matter, percent sand, percent clay, percent rock fragments, bulk density, and initial soil water. Runoff and site variables include longitude, latitude, elevation, slope, and aspect.

Water enters the system as precipitation, and may leave the system as runoff, deep drainage, evaporation, or plant transpiration (Figure 5). As water accumulates in the soil, progressively deeper soil layers are filled to field capacity, and excess water drains to the next layer. Water may be lost from the system as runoff, or if layers are filled may move out to the system as deep drainage. Soil evaporation and plant transpiration, in that order, remove water from the soil profile, beginning with the uppermost layer. Potential evapotranspirative demand is calculated with the Jensen and Haise (1963) evapotranspiration equation. The potential demand is partitioned into potential transpiration and potential evaporation; values are used to calculate actual transpiration and evaporation (Johnson, 1985).

Output from the Rangetek model is in the form of a yield index. The yield index calculated by the model is an estimate of plant growth for current climatic conditions and site parameters, and is expressed as a percent of site potential yield (Johnson, 1985). This cumulative index equals the ratio of actual transpiration to potential transpiration. The index, or predicted total plant yield, is calculated on the date that peak standing crop occurs. The product of site potential yield (kg/ha) and the yield index (%) therefore provides an estimate of cumulative production (Johnson, 1985). The yield index is a good indicator of the growing season climate as it relates to plant growth and enables comparisons of range treatments or vegetation inventories among years or range sites by accounting for a large portion of climate induced variation in plant response (Wight, 1987).

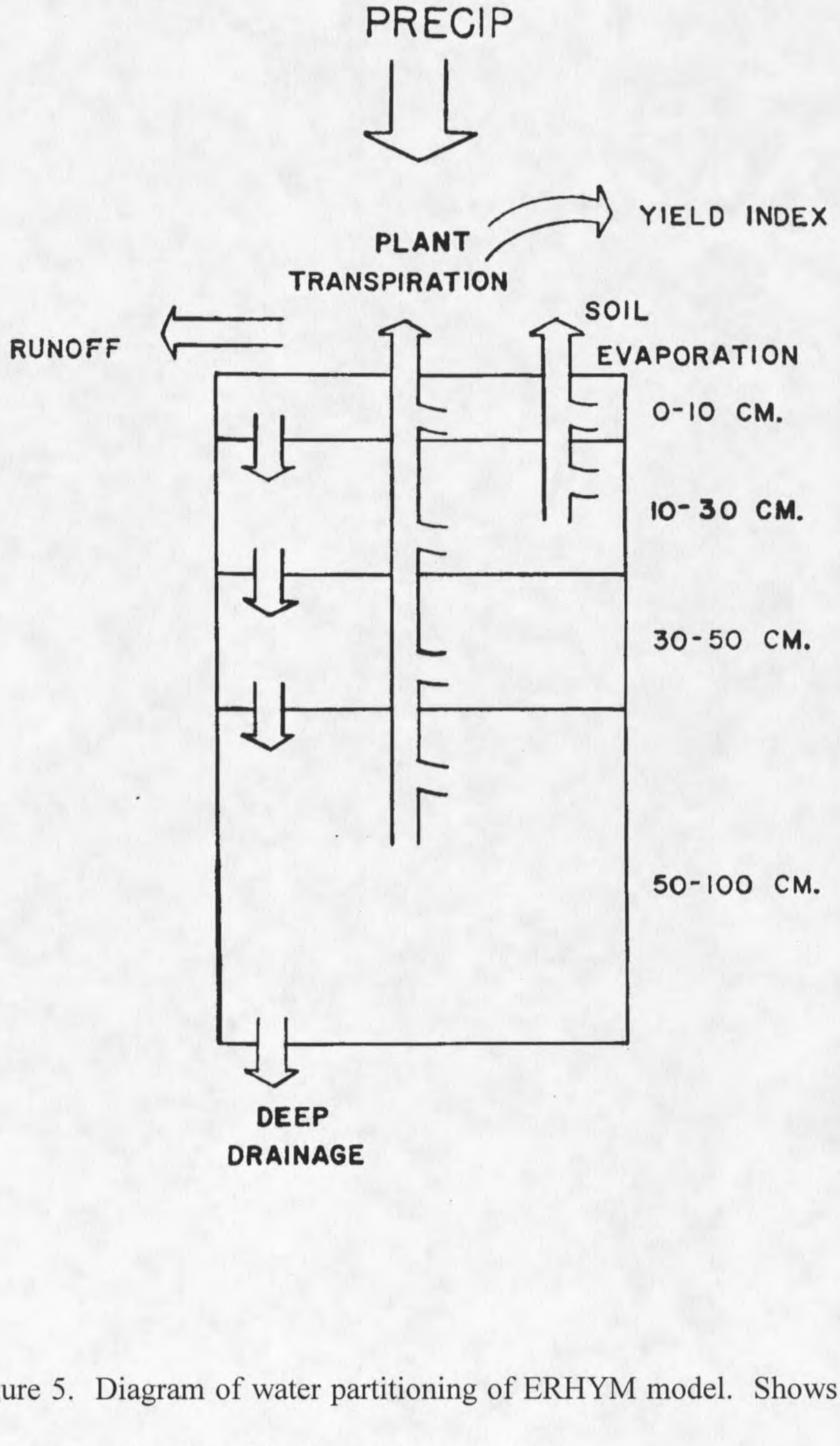


Figure 5. Diagram of water partitioning of ERHYM model. Shows major water flows through layered soil profile (from Johnson, 1985).

Miles City Data

Site and vegetation data were collected from the Fort Keogh Livestock and Range Research Laboratory near Miles City, Montana (46° 22' N 105° 5' W). Regional topography ranges from rolling hills to broken badlands with small intersecting streams that flow into large permanent rivers meandering through broad nearly level valleys (Heitschmidt et al., 1993). Climate is semi-arid with vegetation dominated by western wheatgrass [*Pascopyrum smithii* (Rydb.) Love], threadleaf sedge [*Carex filifolia* Nutt.], needle and thread [*Stipa comata* Trin. And Rupr.], blue grama [*Bouteloua gracilis* (H.B.K.)], and downy [*Bromus tectorum* L.] and Japanese bromes [*B. japonicus* Thunb.] (Grings, 2002). Average rainfall in the area is 338 mm with 60% received during the 150-day, mid-April to mid-September growing season. Average daily temperatures range from -10°C in January to 24°C in July with daily maximum temperatures occasionally exceeding 37°C during summer and daily minimum occasionally dipping below -40°C during the winter (Heitschmidt et al., 1993).

Daily precipitation and temperature data were obtained from National Oceanic and Atmospheric Association (NOAA) (1970-1999) and formatted to fit the Rangetek model (year, Julian date, maximum temperature (°F), minimum temperature (°F), and daily precipitation (inches)). Fort Keogh provided data to characterize climatic, site, and forage production conditions for the area near Miles City. Rangetek was parameterized for each site (n=12) where all input information was available (Tables 4 and 5). The dataset consisted of three years of clip data (1991, 1992, 1993) for 12 different range sites. Each site was classified by soil series type. General soil characteristics were found in the NRCS survey for Custer County. Initial soil water percentage for all sites was reported by Heitschmidt et al. (1999).

Table 4. Site Variables for Miles City, Montana

Soil Series Type	Site	Range Site	Aspect	Elevation (m)	Slope %
Cabbart	6	Shallow	NNE	2600	8
Cabbart	16	Shallow	NNE	2640	6
Cambeth	8	Thin Silty	NEE	2720	15
Creed	7	Claypan	SSE	2540	1
Ethridge	14	Clayey	N	2642	1
Kobase	3	Clayey	ESE	2424	5
Twilight	12	Thin Sandy	E	2560	15
Twilight	13	Sandy	SWS	2660	18
Yamacall	5	Silty	NE	2540	10
Wabek	15	Shallow to Grvl	N	2622	1
Wabek	17	Shallow to Grvl	NW	2570	10
Wabek	18	Shallow to Grvl	SE	2600	18

Table 5. Vegetation Variables for Miles City, Montana

Soil Series Type	Site	Average Yield[a] (kg/ha)	Grass %	Bare Ground %	Leaf Area Index[b]
Cabbart	6	926	75	35	1.74
Cabbart	16	879	75	35	1.65
Cambeth	8	890	90	25	1.47
Creed	7	1286	75	40	2.41
Ethridge	14	1133	75	20	2.12
Kobase	3	1532	70	20	2.99
Twilight	12	976	85	27	1.68
Twilight	13	1001	85	10	1.73
Yamacall	5	1301	85	5	2.24
Wabek	15	893	65	30	1.81
Wabek	17	641	65	30	1.30
Wabek	18	1233	65	30	2.50

[a] Average Yield is the forage production data averaged over three years for each site.

[b] Leaf Area Index is the ratio of living leaf area to ground surface. It considers multiple layers of leaves and is different than canopy cover.

Lethbridge, Alberta Data

Climatic, site, and vegetation data were collected at the Agriculture Canada Research Substation, Manyberries, near Lethbridge, Alberta. The soil was a loamy Aridic Haploboroll, and vegetation belongs to the *Stipa-Bouteloua* faciation of the Mixed Prairie Association. Principal forage species include needle-and-thread (*Stipa comata*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), junegrass (*Koeleria cristata*), Sandberg's bluegrass (*Poa secunda*), and threadleaf sedge (*Carex filifolia*), in order of decreasing yield (Smoliak, 1986).

Daily precipitation and temperature data were obtained from the Manyberries Experiment Station in Lethbridge, Alberta (1930-1987), where the data were recorded at the Substation. Smoliak (1986) previously published forage production data from this site. During 1930-1987, 15 (0.84 m^2) plots were clipped annually. These plots were restricted from grazing with the use of portable cages, which were distributed randomly in pastures that were moderately grazed by cattle. All plant growth found inside the cages was removed during the previous fall to determine an accurate measurement of current year's growth. Sites were hand clipped to the ground after the forage was mature, usually late September.

The Rangetek model was parameterized for the Alberta site (Table 6 and 7). Manyberries provided climatic, site, and forage production data from the study done by Smoliak (1986). Site variables included Wardlow soil series type, north aspect, an elevation of 938 m, and a slope of 3%. Vegetation variables included an average yield of 388 kg/ha, 79% gramminoids, 30% bare ground, and a leaf area index of 0.70. General soil parameters for the Alberta site were found in the Canadian Soil Series survey.

Statistical Analyses

The data were collated to correspond to the growing season year to enable a measure of agricultural drought as defined by Kulshreshtha (1989) and Thurow and Taylor (1999). The growing season year was defined as monthly precipitation from August to July. Multiple regression methods were used to determine the effects of the climatic factors on range forage production -- i.e., simulated yield index at both locations and actual yield at Manyberries. The stepwise multiple regression procedure was used to select the most accurate prediction equations (SAS Inst. Inc., Cary, NC). Independent, or predictor, variables used were monthly precipitation and maximum monthly temperatures. Variables remained in the model only at an α-level of 0.05. First, best predictors were identified using all data available (monthly temperature and precipitation). A second set of predictors was identified constraining the predictor variables to months prior to July. Because temperature variables contributed little to the predictive ability of the equations, a third set of equations was developed using only monthly precipitation prior to July.

CHAPTER SEVEN

OBJECTIVE ONE
PREDICTOR OF FORAGE PRODUCTION
RESULTS AND DISCUSSION

Results presented include a short description of the climatic data set and regression equations developed from simulated yield index and actual forage data.

Miles City, Montana

Measured precipitation over the 30-yr period was quite variable. Averages for precipitation, maximum and minimum temperatures are located in tables 6-7. The highest annual precipitation recorded was 51.51 cm in 1978 and the lowest annual precipitation was 13.39 cm in 1988. Mean annual precipitation for the area was 35.22 cm. On average, 72% of the annual precipitation fell during the growing season (April – September) and 61% of growing season precipitation fell during spring (April – June). May and June have the highest average monthly precipitation, 6.32 and 5.54 cm, respectively. These two months also have the highest variation in precipitation. This could reflect some of the tendency for drought.

The warmest average maximum temperature occurred in June, July, and August, 27.8, 31.7, 28.3 °C, respectively. The high temperatures and low precipitation in late summer coincide with summer dormancy and a yearly drought-like experience during that time. Simple correlations among monthly precipitation and maximum average temperature variables are presented in Appendix A.

Table 6. Average Monthly Precipitation for Miles City, Montana.

Month	Precipitation (cm)	Standard Deviation	CV
January	1.05	1.07	1.02
February	1.15	1.02	0.89
March	2.68	2.38	0.89
April	3.54	3.18	0.90
May	6.33	4.25	0.67
June	5.55	3.68	0.66
July	3.25	2.57	0.79
August	3.25	2.66	0.82
September	3.28	2.49	0.76
October	2.67	3.33	1.25
November	1.16	1.18	1.02
December	1.34	0.91	0.68
Total	35.22	11.12	0.32

Table 7. Average Maximum and Minimum Monthly Temperature (°C) for Miles City, Montana.

Month	Maximum Temperature	Standard Deviation	Minimum Temperature	Standard Deviation
January	-0.82	6.05	-13.75	5.03
February	3.28	6.17	-9.77	4.99
March	9.69	4.42	-4.69	2.38
April	16.97	3.94	1.22	1.76
May	22.64	3.49	7.16	1.36
June	27.95	2.95	12.39	1.61
July	31.38	1.91	15.58	1.56
August	28.49	3.54	14.89	1.89
September	20.36	3.88	8.24	1.71
October	12.28	5.03	1.72	1.32
November	3.93	4.04	-5.79	2.81
December	-1.07	4.50	-11.69	4.02

Using all available climatic data, the best prediction equation for simulated yield index included April and May precipitation, January and July average maximum temperature and May minimum temperature (R^2=0.87, Table 8). Constraining predictor variables to those measured prior to July, the resulting equation included previous October and November, April and May precipitation and April minimum temperature

(R^2=0.89). The last step was to constrain variables to only precipitation prior to July because temperature explained very little of the variation in simulated yield index (table 9). The final equation included previous October and November, April and May precipitation as predictors of simulated yield index (R^2=0.84).

It is interesting to note that all of the temperature variables, whether maximum or minimum, had negative coefficients (table 8). This described the relationship between temperature and forage yield index to be negative, where as temperature rose forage yield index decreases and vice versa. The partial R^2 values showed that the temperature variables explain only a small amount of variation and that temperature predictors vary depending on the constraints of the model (table 9).

Table 8. Regression equations predicting simulated forage yield index from precipitation and temperature data – Miles City, Montana.

	Regression Equations	R^2	MSE*
1	Y = 1.348 + 0.037 (April Precip) + 0.018 (May Precip) + -0.005 (January Max Temp) + -0.031 (July Max Temp) + -0.034 (May Min Temp)	0.87	0.155
2	Y = 0.048 + 0.041 (April Precip) + 0.023 (May Precip) + 0.014 (Previous October Precip) + 0.039 (Previous November Precip) + -0.025 (April Min Temp)	0.89	0.158
3	Y = 0.008 + 0.041 (April Precip) + 0.020 (May Precip) + 0.015 (Previous October Precip) + 0.044 (Previous November Precip)	0.84	0.186

*MSE units are index units^2

1 Equations developed using all available climatic variables (precipitation, max and min temperatures)

2 Equations developed using all variables prior to July

3 Equations developed using only precipitation variables prior to July

Table 9. Partial R^2 of variables for each regression equation for Miles City, Montana

Variable	Partial R^2 for Regression Equations 1	2	3
April Precip	0.39	0.39	0.39
May Precip	0.29	0.29	0.29
January Max Temp	0.03		
July Max Temp	0.10		
May Min Temp	0.06		
April Min Temp		0.08	
Previous October Precip		0.06	0.08
Previous November Precip		0.06	0.07
Total	0.87	0.89	0.84

1 Equations developed using all available climatic variables (precipitation, max and min temperatures)
2 Equations developed using all variables prior to July
3 Equations developed using only precipitation variables prior to July

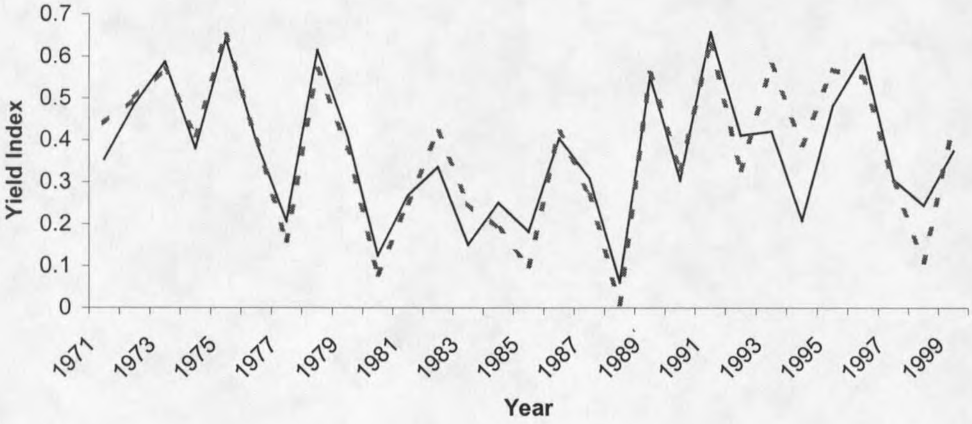


Figure 6. Simulated yield index output from Rangetek (dashed line) and the predicted yield index (solid line) using the model developed from precipitation variables prior to July for Miles City, Montana.

Figure 6 shows the ability of Equation 3 to detect emerging drought by plotting the predicted index values against the simulated yield index output from Rangetek. The trend of the model prediction follows closely to the simulated yield, where the model predicts drops in yield index but falters in predicting the intensity of drought 3 years out of the 30 yr studied. The model also predicts drought when there might not be one twice during the 30-yr period.

Lethbridge, Alberta

Measured precipitation over the 50-yr period was quite variable. Averages for precipitation, maximum and minimum temperature are located in tables 10 and 11. The highest annual precipitation recorded was 60.88 cm in 1965 and the lowest annual precipitation was 20.55 cm in 1943. Mean annual precipitation for the area was 32.81 cm. On average 67% of the annual precipitation fell during the growing season (April – September) and 61% of growing season precipitation fell during spring (April – June). May and June had the highest average monthly precipitation, 4.12 and 6.22 cm, respectively. The warmest average maximum temperature occurred in June, July, and August, 22.27, 27.42, 26.49 °C, respectively.

Correlations between actual forage yield and different measures of precipitation were similar to those described by Smoliak (1986) when the climatic data were collated by calendar year (Appendix B). For our analyses, data were collated by growing season and data from the 1942 growing season were removed as outliers (recorded extremely high forage production). Therefore, due to differences in the analyses of and objectives for the data, results reported here are different than those reported by Smoliak (1986).

Simple correlations among monthly precipitation, maximum and minimum temperature variables are presented in Appendix C.

Table 10. Average Monthly Precipitation for Lethbridge, Alberta

Months	Precipitation (cm)	Standard Deviation	CV
January	2.16	1.62	0.75
February	1.82	1.61	0.88
March	2.20	1.64	0.75
April	2.97	2.70	0.91
May	4.12	2.91	0.71
June	6.22	3.75	0.60
July	3.23	2.33	0.72
August	2.95	2.23	0.76
September	2.47	2.02	0.82
October	1.54	1.39	0.90
November	1.54	1.28	0.83
December	1.87	1.39	0.74
Total	32.81	8.86	0.27

Table 11. Average Maximum and Minimum Monthly Temperature (°C) for Lethbridge, Alberta

Month	Maximum Temperature	Standard Deviation	Minimum Temperature	Standard Deviation
January	-6.93	5.88	-18.19	5.47
February	-4.02	5.44	-15.09	4.83
March	1.55	4.03	-9.88	3.28
April	11.23	3.39	-1.86	2.15
May	18.14	2.29	4.29	1.36
June	22.27	2.09	8.69	1.19
July	27.42	1.94	11.66	1.16
August	26.49	2.22	10.74	1.37
September	20.11	2.75	5.15	1.70
October	13.32	2.77	-0.85	1.63
November	3.50	3.77	-8.58	2.98
December	-2.93	4.15	-14.21	3.75

Simulated Forage Data

The best regression equation predicting simulated forage yield index included only April and May precipitation (R^2 = 0.44, Table 12). The model was the same no matter the level of restriction on the variables. The model developed from the simulated data from Lethbridge explained much less of the variation seen in the yield index than the model for Miles City. This may be due to chance or fundamental differences in locations. The growing season tends to be shorter for Lethbridge than Miles City, as seen where below freezing average monthly temperatures prevail in Lethbridge between October and April, and in Miles City below freezing average monthly temperatures occur only November through March.

Although the model explained less variation, the plotted residuals (Figure 7) show the relative trend of predicted yield followed the simulated output from Rangetek. The model failed to detect the intensity of drought, but consistently detected drops in yield index. Two out of fifty years the model predicted an decrease in the yield index when there was an increase, and once predicted an increase in the yield index when there was a decrease.

Table 12. Regression equation predicting simulated forage yield index from precipitation and temperature data – Lethbridge, Alberta.

Regression Equations	R^2	MSE*
Y = 0.320 + 0.014 (April Precip) + 0.016 (May Precip)	0.44	0.101

*MSE units are index units^2

Table 13. Partial R^2 of variables for the regression equation for Lethbridge, Alberta

Variable	Partial R^2 for Regression Equations
April Precip	0.14
May Precip	0.30
Total	0.44

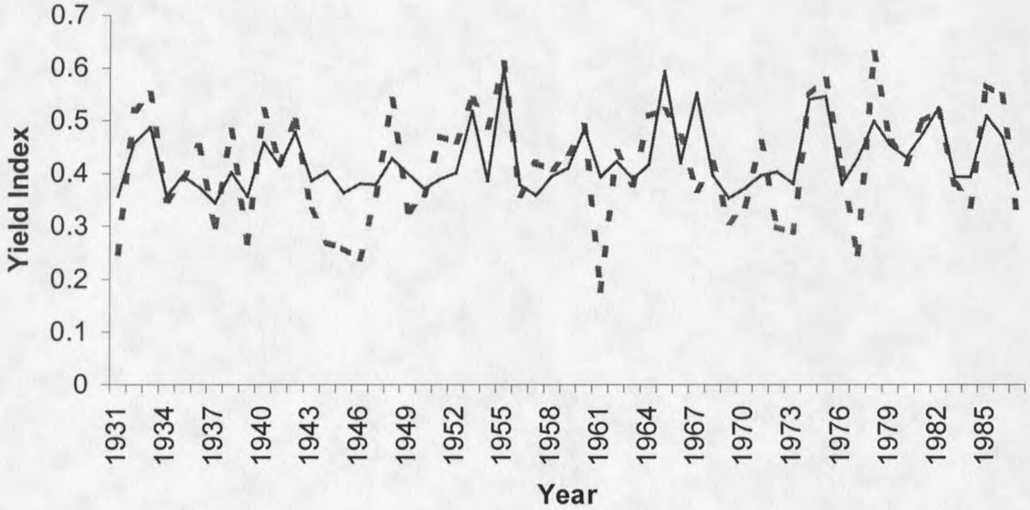


Figure 7. Simulated yield index output from Rangetek (dashed line) and the predicted yield index (solid line) using the model developed from precipitation variables prior to July for Lethbridge, Alberta.

Actual Forage Data

Using all available climatic data, the best prediction equation for actual forage yield (clipped annually in September) included April, June, and July precipitation, plus April maximum temperature and June and November minimum temperature (R^2=0.71, table 14). Constraining predictors to those measured prior to July yielded an equation that included April, May, June, and September precipitation, January maximum temperature, and previous year's August minimum temperature (R^2=0.66). Using only precipitation variables, the best equation included April, May, June, and February (R^2=0.56). February precipitation only explained 7% of the variation in actual forage yield (table 15), however, its biological significance is suspect because such little precipitation is experienced and the soil would be frozen limiting it's effect. Therefore, February precipitation was removed, and the resulting equation included April, May, and June (R^2=0.50).

As was found in Miles City, all of the temperature variables had negative coefficients (table 14). This described the relationship between temperature and forage yield index to be negative and consistent between the two locations. Table 15 shows the partial R^2 values which was again consistent with Miles City, where the temperature variables explained only a small amount of variation. July precipitation did have a relatively high partial R^2 value when predicting actual forage data. This might suggest that July precipitation may actually influence forage growth.

The residuals plotted for the actual forage production data (figure 8) show that, again, the trend between predicted and observed is closely related, but intensity of drops in forage production was not predicted well. This would suggest that a producer using this information may predict drought more often than actually occurs.

Table 14. Regression equations predicting actual forage yield from precipitation and temperature data – Lethbridge, Alberta.

	Regression Equations	R^2	MSE*
1	Y = 547.08 + 15.38 (April Precip) + 13.74 (June Precip) + 28.13 (July Precip) + -11.79 (April Max Temp) + -38.04 (June Min Temp) + -8.98 (November Min Temp)	0.71	126,393
2	Y = 378.85 + 22.91 (April Precip) + 18.14 (May Precip) + 16.77 (June Precip) + 19.89 (September Precip) + -7.00 (January Max Temp) + -32.83 (August Min Temp)	0.66	117,055
3	Y = 93.63 + 24.64 (February Precip) + 26.33 (April Precip) + 11.94 (May Precip) + 18.69 (June Precip)	0.56	151,556
3b	Y = 136.77 + 30.01 (April Precip) + 12.76 (May Precip) + 16.68 (June Precip)	0.50	180,103

*MSE units are $(kg/ha)^2$

1 Equations developed using all available climatic variables (precipitation, max and min temperatures)

2 Equations developed using all variables prior to July

3 Equations developed using only precipitation variables prior to July

Table 15. Partial R^2 of variables for each regression equation for Lethbridge, Alberta

	Partial R^2 for Regression Equations			
Variable	1	2	3	3b
February Precip			0.07	
April Precip	0.28	0.28	0.28	0.28
May Precip		0.05	0.05	0.05
June Precip	0.17	0.17	0.17	0.17
July Precip	0.15			
September Precip		0.06		
January Max Temp		0.04		
April Max Temp	0.03			
June Min Temp	0.06			
August Min Temp		0.06		
November Min Temp	0.03			
Total	0.71	0.66	0.56	0.50

1 Equations developed using all available climatic variables (precipitation, max and min temperatures)

2 Equations developed using all variables prior to July

3 Equations developed using only precipitation variables prior to July

3b Equation developed the same as 3 and removing February from possible variables

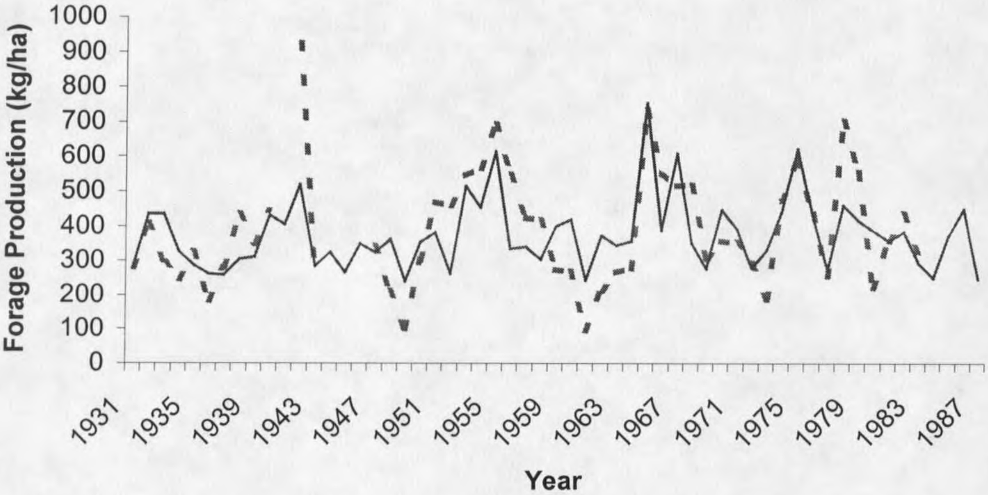


Figure 8. Plot of the residuals for Lethbridge, Alberta. The actual forage production (dashed line) vs predicted forage production (solid line) forage production data.

Comparing the simulated yield index values and the actual forage production data from Manyberries suggests that Rangetek may be overly sensitive to the months of April and May and less sensitive to summer precipitation than the actual data. This suggests that the usefulness of Rangetek may be limited. However, both actual and simulated data sets revealed that spring and early summer are reliable predictors of drought. Figure 9 plotted the actual forage production data against simulated yield index values. The simulated yield index from Rangetek did follow the relative trend of the actual forage data ($r = 0.587$, *P*-value < 0.01). Although the simulated yield index found 3 out of 50 years drought when there was not, this reaffirms the usefulness of Rangetek in determining early predictors of forage production.

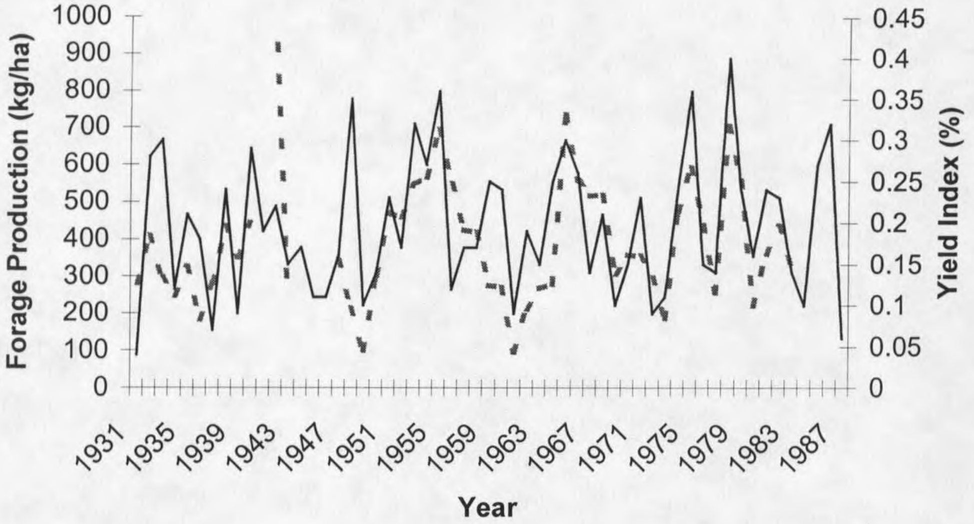


Figure 9. Simulated yield index values from Rangetek (solid line) and actual forage production data (dashed line) for 50 years at Lethbridge, Alberta.

Discussion

Forage production, simulated and actual, can be predicted with some confidence from spring (April through June) precipitation at both Miles City and Lethbridge. Our approach was to develop an early practical predictor to detect emerging drought and although temperature variables and July precipitation added reliability to the models statistically, it decreased the usefulness as an early and/or practical predictor for cow-calf producers. Temperature and July precipitation variables increased the ability of the regression equations to explain the variation seen in forage production, but the proportion of the variation explained by each variable was small and extremely variable. It is also not always practical for producers to collect average temperature measurements.

Table 2 shows that the vast majority of the research done in the last 70 years has shown that some measure of precipitation is one of the most important factors in forage growth. Sneva and Hyder (1962a,b) performed similar work utilizing yield indices and found in semi-arid closed communities of native or well-adapted introduced species fluctuate with precipitation indices in a fairly uniform and predictable manner when date were collated during a crop-year. Wight et al. (1984) used the Rangetek model to relate soil water and climatic parameters to plant growth. They found that two-thirds of the field measured yields were within one standard deviation of forecasted yields for the April, May and June forecasts using 55 years of weather records and 12 years of actual yield and soil water data. Hanson and Wight (1991) compared long-term historical and the stochastically generated weather records in terms of their statistical attributes and effects on herbage yield and runoff forecasts calculated from the Rangetek model simulations. Yield forecasts were similar using either historical or synthetic weather records.

Our results suggest that predictions based on spring precipitation could be used effectively to make management decisions as early as July 1st. Sneva and Hyder (1962a,b) in eastern Oregon and Smoliak (1956) in Southern Alberta declared that predictions of forage production could by utilized by July 1st as well. This is in contrast to Smoliak (1986) who suggested that the best predictions could be made by August 1st. The usefulness of such a prediction (i.e., August) would be for changing fall or winter grazing plans, or to prepare grazing plans for the next year. This prediction would occur too late in the growing season to effectively change management in response to drought. The purpose of early predictors of forage production is for the detection of drought to permit greater flexibility in management for producers.

It has been shown that use of prediction equations should be limited to areas of similar vegetation and soil type (Cannon and Nielson, 1984). Differences in equations developed for Fort Keogh and Manyberries appear to support this concept. However, for the specific purpose of early prediction of drought, all of the models define spring and early summer as predictors of forage production.

Implications

Ranchers can use weather records to reasonably forecast forage production by July 1st. Practically, forage produced by early July is a good indicator of growing season forage production. They can then detect emerging drought and change management strategies early in the growing season to forestall some of the negative impacts of drought on range resources and livestock performance.

CHAPTER EIGHT

OBJECTIVE TWO

EVALUATION OF DROUGHT MANAGEMENT STRATEGIES

MATERIALS AND METHODS

Objective one identified spring (April and May) and early-summer (June) precipitation as practical predictors of forage growth. The prediction can be done as early as July 1st to forecast forage production for the rest of the growing season. Management decisions can then be made based on the forecasted forage production at that time. Therefore objective two was to determine the effects of manipulating management strategies during drought on enterprise profitability.

Our approach used two bioeconomic computer models to simulate changes in enterprise profitability of cow-calf production systems in response to different management scenarios during drought. The MSU beef production system model (Tess and Kolstad, 2000a) was parameterized to represent a hypothetical cow-calf enterprise in the Northern Great Plains. The MSU model simulated cattle performance and ranch profit for each specified management scenario. Tess and Kolstad (2000a,b) and Tess (1999) present more detailed descriptions of the simulation model and illustrate its performance. The U.S. Meat Animal Research Center (MARC) model modified by Williams and Bennett (1995) was used to simulate a drylot scenario for early-weaned calves. Keele et al. (1992), Williams et al. (1992), Williams and Bennett (1995), and Williams et al. (1995a,b,c) present more variations of usage and detailed descriptions of the simulation model and its performance.

Montana State University Beef Production Systems Model

The MSU model is dynamic model where both stochastic and deterministic functions are utilized. The stochastic functions relate mostly to reproduction and the deterministic functions are used for growth and metabolism. The model estimates individual animal performance daily over a lifetime and performance of a number of individuals as a herd annually. Cattle performance is determined by the interaction of many different factors including genetic potential, physiological state, and feed availability and quality. Physiological state of each animal is determined by many components including age, weight, body composition, stage of gestation, and state of lactation. Growth and body composition is a function of genetic potential, nutrient intake, and age. Puberty, anestrus, postpartum interval, body composition, and weight of cow are components that establish the reproductive status of the cows. Lactation is determined by the cow's genetic potential. Priority of nutrient partitioning is determined by physiological state of the cow and by nutrient intake.

There are several types of inputs required by the model including livestock, managerial, forage, and economic parameters. Livestock parameters include mating system, genotype, mature weight, peak milk yield, postpartum interval, and calf mortality. Managerial inputs include dates for range turn out and removal, type and amount of stored or supplemented forages, management groups, breeding and calving dates, weaning date, replacement rate, culling rate and herd size. Forage inputs include annual amount and chemical composition of range, hay production, and supplements (i.e., metabolizable energy, crude protein, rumen degradable protein, and neutral detergent fiber). Economic parameters consist of market prices for animals sold and variable costs associated with supplemental feeding, veterinary services and vaccinations, bulls, livestock taxes, opportunity costs, and labor.

Model outputs include herd size for a fixed forage resource base, weaning weight per cow exposed (CWCE), purchased feed costs, break-even steer prices (measures cost of production per unit of steer-equivalent weight sold), average calf weaning weight (AWW), and ranch gross margin (RGM). Ranch gross margin is defined as gross income less variable costs. Variable costs include purchased feed, health expenses, property taxes, bull expenses, marketing, labor, and interest.

The model was parameterized to represent a hypothetical cow-calf enterprise in eastern Montana, similar to the spring calving scenario described by Reisenauer (2001). The hypothetical ranch was developed to represent typical management in the Northern Great Plains region during an average climatic year. This was the baseline whereby all treatments were applied. Changes in management, level of drought, purchased hay cost and forage quality were then simulated in a factorial arrangement to reflect effects of emerging drought.

Base Management System

Tess (1999) and Reisenauer (2001) reported many of the livestock parameters used in this study. The base management system was characterized by inputs required to maintain a herd size of approximately 511 cows during an average climatic year. Herd size was the number of cows exposed to breeding including 70 replacements. Table 16 presents production and management values for the base system.

Table 16. Production and management characteristics of base system

Item	Base value
Cow exposed (herd size)	511
Cow mature wt, kg	560
Average calf weaning wt, kg	245
Peak milk yield, kg/d	12
Start of breeding season	June 5
Length of breeding season, d	60
Cows/bull	25
Weaning and sale date	October 31
Turnout to native range	May 1
Begin hay feeding	January 1
Weight weaned per cow exposed, kg	210

The mating system was a two-breed rotational system at equilibrium using Angus and Hereford cattle (Tess, 1999). Cows were culled if they were nonpregnant, unsound, or were 13 yr of age. Calves and cull females were sold immediately after weaning.

The MSU simulation model determined annual animal unit months (AUM; 304 kg DM/mo; SRM, 1989) of range forage required to sustain a herd size of 511 cows under the base management (4,329 AUM). This number of AUM was then fixed at that level as the range available during an average climatic year. Hay production was also fixed to the requirements of the base system. The forage resources for the ranch on an average climatic year and typical management were 4,329 AUM of range forage, plus 571 t grass and 189 t alfalfa hay. If hay was not used within a year the value of that left over was credited to ranch income at market value. If extra hay was needed it was purchased at market value.

During the winter-feeding period alfalfa hay (DM basis: 2.1 Mcal ME/kg, 17% CP, 46% NDF) was fed to replacement heifers and bred yearlings. Alfalfa/grass hay (DM basis: 2.0 Mcal ME/kg, 14% CP, 55% NDF) was fed to mature cows from range removal through turnout to grass May 1. Protein supplements (DM basis: 3.1 Mcal

ME/kg, 12% and 20% CP) were provided as needed after calving, weaning and during the winter-feeding period. Refer to table 17 for supplementation strategies for the base system. Quality parameters for hays fed (Julien and Tess, 2002) and domestic pastures grazed (Adams and Short, 1987) were assumed to be representative of the Northern Great Plains region.

Economic inputs simulated by the model were valued at regional 1999 prices (Table 18).

Table 17. Supplemental strategies for the base system during an average climatic year.

Management Group	Supplemental Periods	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	October 31 to January 1	1.0 kg Cubes – 20% CP
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	October 31 to January1	1.5 kg Cubes – 20% CP
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	October 31 to January 1	1.5 kg Cubes – 20% CP

Table 18. Input prices used in the simulations

Item	Value
Feed	
Alfalfa hay, \$/t	68.04
Grass hay, \$/t	58.97
Supplement, 12% CP, \$/t	125.00
Supplement, 20% CP, \$/t	180.00
Native range, \$/animal unit month	13.00
Marketing	
Brand inspection and checkoff, \$/animal	1.30
Commission on cows, %	2
Commission on calves, %	2
Shrink of calves, %	2
Shrink of yearlings and cows, %	3.5
Trucking, \$/kg/km (100 km)	0.0076
1999 Cattle Prices	
Steers, \$/100 kg	200.13
Slide[a]	0.11
Heifers, \$/100 kg	189.99
Slide[a]	0.09
Yearling heifers, \$/100 kg	166.54
Cull Cows	75.70
Dystocia, \$/incidence	16.00
Annual expenses[b], \$/animal	
Steer calves	10.86
Heifer calves	10.86
Yearling heifers	39.07
Two-year-old cows	45.46
Mature cows	46.07
Bulls	577.43
Interest on variable expenses, %	10

[a] Slide is the change in price per kg change in weight.

[b] Include vaccinations, property taxes, opportunity cost of investment (5% for yearlings and older), miscellaneous health treatments, ear tags, and depreciation (\$427, bulls only).

Simulations

Treatments were arranged in a 4^2 factorial design. Factors examined were management strategy (**early**, management altered by July 15th vs **normal**, management not altered), level of drought (**moderate**, 20% reduction in available forage vs **severe**, 40% reduction in available forage), purchase hay cost (**average**, grass hay \$58.97/t and alfalfa hay \$68.04/t vs **high**, grass hay \$77.11/t and alfalfa hay \$86.18/t), and forage quality (**average** crude protein (CP), metabolizable energy (ME), and neutral detergent fiber (NDF) vs **drought** affected CP, ME, and NDF). For each treatment, herd size and average weaning weight (where applicable) were maintained. The cattle were managed to maintain performance and not damage the range resource. Other strategies, which allow cattle performance to decline or a decrease in herd size, were not considered in this study.

The normal management (NM) scenario included no 'early' management changes to emerging drought, but no decline in animal performance was permitted. Cows were fed hay and/or purchased supplements to maintain performance, herd size, and average calf weaning weight. The early management (EM) scenario implemented by July 15th included weaning calves at an average 90d of age, culling dry cows at weaning and culling aged and nonpregnant cows 45 d after the start of breeding season to reduce grazing pressure on the stressed forage resource.

Due to the scarcity of research describing a quantitative relationship between lack of precipitation and intensity of drought, two levels of drought were chosen to consider the changes in intensity and duration of drought on enterprise profitability. Level of drought was defined as moderate (20% reduction in available forage) and severe (40% reduction in available forage) where both levels of drought were deviated from the base system (Table 19). Normally, the fixed AUM level allowed for increased or decreased cow numbers to be run on range in order to match forage harvested with that available. Our objective for this study was to manipulate the amount of forage available to simulate differing levels of drought and maintain a constant herd size. Therefore, if level of drought caused a forage deficiency significant to reduce the herd size, cattle were supplemented. Refer to table 20 for changes in characteristics of the production scenarios and tables 21-24 for changes in the supplemental strategies due to management and level of drought.

Table 19. Changes in forage parameters due to level of drought.

	Level of Drought		
Item	Average Climatic Year	Moderate (20% Reduction)	Severe (40% Reduction)
Range forage, AUM	4329	3463	2597
Grass hay, t	189	151	113
Alfalfa hay, t	571	457	343

Table 20. Characteristics of production scenarios

	Normal Management Normal Conditions	Normal Management Mod. Drought	Normal Management Sev. Drought	Early Management Mod. Drought	Early Management Sev Drought
Weaning Date	Oct 31	Oct 31	Oct 31	July 15	July 15
Cull Date	Oct 31	Oct 31	Oct 31	July 15 Sept 15	July 15 Sept 15
Range Removal	Jan 1	Oct 20	Sept 5	Jan 1	Oct 2

Cull Date – for Early Management scenarios, drys culled at weaning and cows not pregnant culled 45 days after breeding season started (June 5)
Range Removal – date cows removed from range and full supplementation started

Table 21. Supplementation for simulated herd during moderate drought and normal management.

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	October 20 to January 1	6.5 kg Alfalfa Hay
	October 31 to January 1	1.0 kg Cubes – 20% CP
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	October 20 to January 1	Ad Lib. Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	August 28 to October 31	0.6 kg Cubes – 12% CP
	October 20 to January 1	Ad Lib. Alfalfa/Grass Hay

Table 22. Supplementation for simulated herd during severe drought and normal management.

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	October 31 to January 1	1.5 kg Cubes – 20% CP
	September 5 to January 1	
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	September 5 to January 1	Ad Lib. Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	September 5 to January 1	Ad Lib. Alfalfa/Grass Hay
	September 5 to October 31	1.7 kg Cubes – 12% CP

Table 23. Supplementation for simulated herd during moderate drought and early management.

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP

Table 24. Supplementation for simulated herd during severe drought and early management.

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	October 2 to January 1	7.5 kg Alfalfa Hay
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	October 2 to January 1	7.5 kg Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	October 2 to January 1	7.5 kg Alfalfa/Grass Hay

During drought, hay prices can increase due to reduced production and limited availability. For this study, two levels of hay cost were used to determine the effect of differences in the price of hay during drought. For the base system, grass hay was priced at \$58.97/t and alfalfa at \$68.04/t. High prices that may be found during drought are reflected in the second set of prices used for hay, grass hay was priced at \$77.11/t and alfalfa at \$86.11/t.

Forage quality may change in response to drought but there is little research quantifying the changes in animal diets. Therefore, two levels of forage quality were used to determine the effect of changes in forage quality on enterprise profitability. Average forage quality curves used in the model were adapted from Adams and Short (1987). Nelson and Moser (1994) described how nutrient concentration in the forage increases during drought due to an increase in leaves and delayed maturity. Sheaffer et al. (1992) found not only an increase in crude protein, but also a decrease in the fibrous portion (NDF and ADF) within the plants that are 'droughted'. However, with decreases in yield associated with drought, grazing animals are forced to consume lower quality forages and forage parts than during a normal year because they have run out of the higher quality forage. Therefore, the forage actually consumed by grazing animals will be lower in crude protein, metabolizable energy, and higher in NDF (Heitschmidt and Grings, personal communication). Figures 10-12 show the forage quality curves reflecting changes in diet during drought that were used in the model. Refer to table 25 for changes in characteristics of the production scenarios and tables 26-29 for changes in the supplemental strategies due to forage quality.

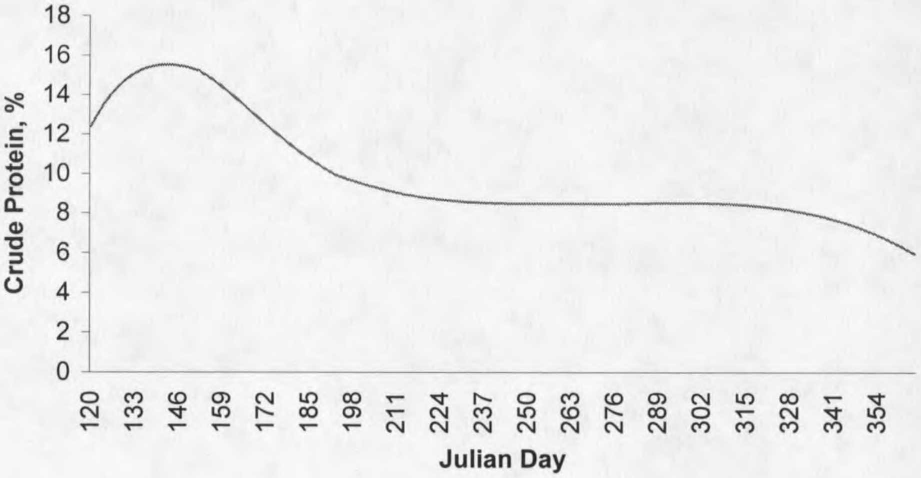


Figure 10. Concentration of crude protein in cattle diets during drought (modified from Adams and Short, 1988).

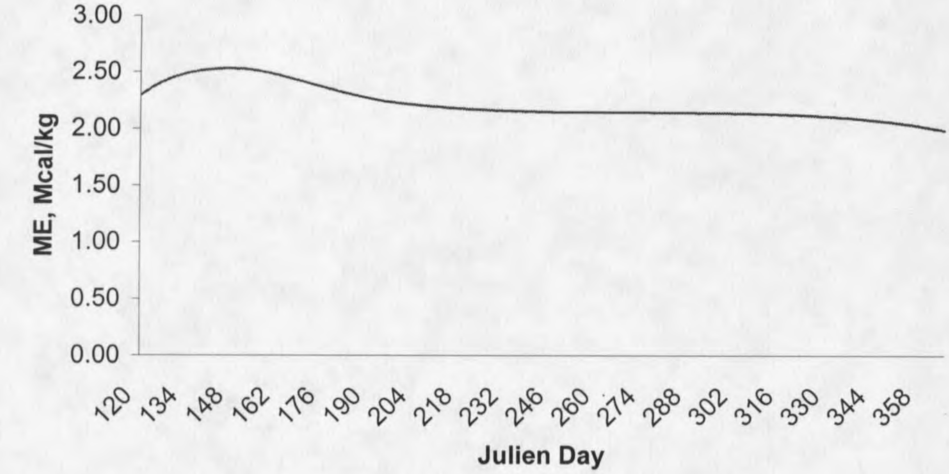


Figure 11. Concentration of metabolizable energy in cattle diets during drought (modified from Adams and Short, 1988).

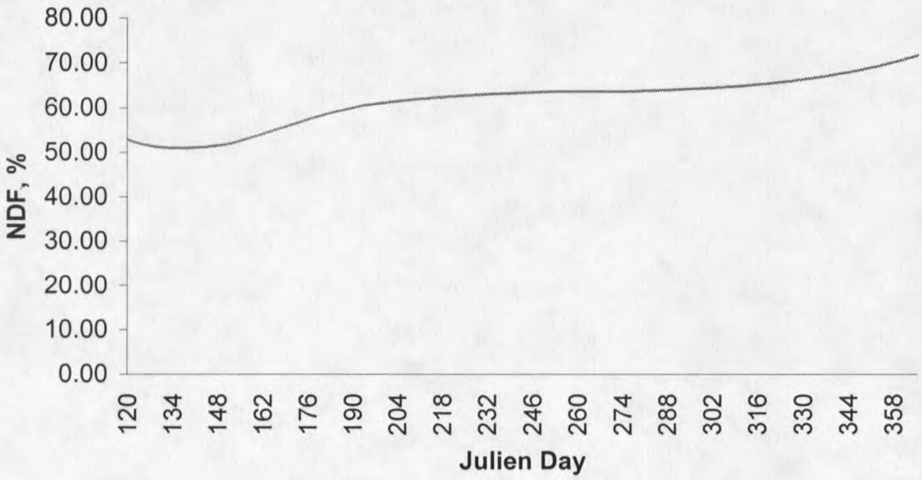


Figure 12. Concentration of neutral detergent fiber in cattle diets during drought (modified from Adams and Short, 1988).

Table 25. Characteristics of production scenarios utilizing drought forage quality

	Normal Management Mod. Drought	Normal Management Sev. Drought	Early Management Mod. Drought	Early Management Sev. Drought
Weaning Date	Oct 31	Oct 31	July 15	July 15
Cull Date	Oct 31	Oct 31	July 15 Sept 15	July 15 Sept 15
Range Removal	Oct 20	Sept 5	Oct. 31	Oct 2

Cull Date – for Early Management scenarios, drys culled at weaning and cows not pregnant culled 45 days after breeding season started (June 5)

Range Removal – date cows removed from range and full supplementation started

Table 26. Supplementation for simulated herd during moderate drought, normal management, and drought forage quality

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
	October 31 to January 1	0.5 kg Cubes – 12% CP
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	September 21 to January 1	1.5 kg Cubes – 20% CP
	October 20 to January 1	6.5 kg Alfalfa Hay
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	October 20 to January 1	Ad Lib. Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	September 21 to January 1	1.5 kg Cubes – 20% CP
	October 20 to January 1	Ad Lib. Alfalfa/Grass Hay

Table 27. Supplementation for simulated herd during severe drought, normal management, and drought forage quality

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
	October 31 to January 1	0.5 kg Cubes – 12% CP
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	September 5 to January 1	1.0 kg Cubes – 20% CP
	September 5 to January 1	6.5 kg Alfalfa Hay
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	September 5 to January 1	Ad Lib. Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	September 5 to January 1	Ad Lib. Alfalfa/Grass Hay
	September 5 to January 1	1.25 kg Cubes – 12% CP

Table 28. Supplementation for simulated herd during moderate drought, early management, and drought forage quality

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	October 31 to January 1	6.5 kg Alfalfa Hay
	October 31 to January 1	1.0 kg Cubes – 20% CP
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
	October 31 to January 1	Ad Lib. Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	October 31 to January 1	6.0 kg Alfalfa/Grass Hay

Table 29. Supplementation for simulated herd during severe drought, early management, and drought forage quality

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
	October 2 to January 1	7.5 kg Alfalfa Hay
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	1.0 kg Cubes – 12% CP
	October 2 to January 1	7.5 kg Alfalfa Hay
Mature Cows	January 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP
	October 2 to January 1	7.5 kg Alfalfa/Grass Hay

The final scenario tested was where early management decisions were made when no drought occurred. The reliability of predicting drought has been discussed in Chapters 6 and 7, and the consequences of such false prediction of drought were simulated using the MSU model. The forage available for the base system during an average climatic year were utilized. The characteristics of the production system were the same as the early management system under moderate drought except that the range removal date was delayed 91 days or until April 1st. Please refer to table 30 for changes in supplemental strategies due to the early management system during an average climatic year. Assumptions used specifically for this scenario were snow cover did not interfere with winter grazing and water was available at all times.

Table 30. Supplementation for simulated herd during an average climatic year and early management.

Management Group	Period	Amount
Replacement Heifers	October 31 to January 1	5.5 kg Alfalfa Hay
Yearlings	January 1 to April 30	6.5 kg Alfalfa Hay
	January 1 to April 30	2.0 kg Cubes – 12% CP
Two-year-old Cows	January 1 to April 30	Ad Lib. Alfalfa Hay
	March 1 to April 30	0.25 kg Cubes – 12% CP
Mature Cows	April 1 to April 30	Ad Lib. Alfalfa/Grass Hay
	March 1 to April 30	1.5 kg Cubes – 12% CP

U.S. Meat Animal Research Center Model

The MARC model is a deterministic model that can simulate differences in the composition of empty body gain of beef cattle, resulting from differences in postweaning level of nutrition that were not associated with empty body weight (Keele et al., 1992). The model is based on four assumptions, as reported by Keele et al. (1992): 1) There is a greater proportion of fat in the empty body gain than in the empty body for cattle growing at intermediate or higher growth rates. 2) Differences in empty body composition caused by plane of nutrition, which are not associated with empty body weight, may be predictable from the rate of empty body weight gain. 3) The full effects of a change in nutrition on empty body composition are not exerted immediately nor are they permanent. 4) If an animal's empty body weight is not changing; its empty body composition approaches an equilibrium value.

The MARC model was used to simulate performance of early-weaned calves from the early management scenario used in the MSU model in a drylot. Williams et al.

(1992) set parameters to predict gut fill. Williams et al. (1995a) provided detailed descriptions of specific inputs for Angus x Hereford cattle. Parameters given for spring calving scenario (Reisenauer, 2001) were modified to represent early-weaned calves in a drylot. Input data from the MSU model included average weight, age and number of steers and heifers from the early management scenario for each level of drought and hay cost.

Rations were balanced to establish diets representative for early weaned calves placed in a drylot. Rations were developed using the Easy Systems Inc. ration balancer. Inputs into the ration balancer consisted of average weaning weight of calves, target average daily gain and target end weight, feedstuffs to be fed, and cost of individual feedstuffs. Early weaned steers and heifers were placed in separate pens and fed a high concentrate diet formulated to contain approximately 14.5% CP (Table 31).

Table 31. Ration for early weaned drylot calves

Item	Amount	
Ingredient, % DM basis	Steers	Heifers
Alfalfa Hay	35.99	28.98
Corn Grain	52.42	56.53
Range Cubes – 30% CP	10.58	13.47
Mineral Mix	1.01	1.02
Chemical Component		
Crude Protein, %	14.64	14.77
NDF, %	24.57	22.49
ADF, %	15.03	13.04
NEm, Mcal	7.53	7.62
NEg, Mcal	5.34	5.49

Diet value parameters included fraction of concentrate, percentage of neutral detergent fiber in the forage fraction, and the physical form of the forage. These variables were needed to calculate weight of gut contents for use in converting full body weight to empty body weight. Feed costs were calculated by the model utilizing metabolizable energy density of the diet and the cost per megacalorie of dietary metabolizable energy. Table 32 summarizes the input diet values for the early-weaned steers and heifers. Differences in feed costs reported reflect the change in cost of hay that may occur during drought, ration composition and cost of other feed ingredients remained the same.

Table 32. MARC diet values, concentrate, NDF, ME, and feed cost for steers and heifers

Item	Amount
Steers	
Concentrate, %	63.97
NDF in forage fraction, %	46.00
ME density	2.74
Feed cost, $/Mcal ME, average hay cost	0.0252
Feed cost, $/Mcal ME, high hay cost	0.0270
Heifers	
Concentrate, %	71.04
NDF in forage fraction, %	46.00
ME density	2.80
Feed cost, $/Mcal ME, average hay cost	0.0265
Feed cost, $/Mcal ME, high hay cost	0.0282

There has been evidence to suggest that early weaned calves will grow more rapidly (Myers et al, 1999b; Fluharty et al., 2000; Barker-Neef et al., 2001), show increased feed efficiency (Myers et al., 1999b), and weigh more (Fluharty et al., 2000) at 205d than calves weaned at six to seven months of age. Our objective for early weaning was to maintain calf weights during drought and evaluate the economic viability of the option. Therefore, early-weaned calves were fed in the drylot to reach a target weight that reflected the performance of the normal weaned calves. Steers and heifers entered the feedlot at a weight of 137 and 124 kg, respectively and were fed to reach a target weight of 249 and 231 kg, respectively. All calves were fed in the drylot for 108 d. Average daily gains for steers were 1.04 kg/d and heifers 1.00 kg/day.

Cumulative Gross Margin

Cumulative gross margin (CGM) was the increase in RGM through the addition of the drylot component for early-weaned calves. Data gathered from the simulations produced by the MSU and MARC models were placed into spreadsheets for analyses of profit and loss due to the drylot option. The MSU model provided the number of steers and heifers, weaning weights, cattle prices, shrink, and RGM. The MARC model supplied the days on feed, feed cost per head per day, yardage and interest costs, and simulated cost of calf mortality. Calf mortality in the drylot was set at 2% as reported by Myers et al. (1999b) for calves weaned at 90d. Myers et al. (1999a,b) found a significant increase in respiratory and digestive morbidity for calves weaned at 90d. This was attributed to the calves not being vaccinated prior to weaning. Although timing might be different, vaccinations were accounted for in the MSU model prior to weaning, therefore, no extra cost was added to the spreadsheet analyses for incidences of sickness, vaccinations, or veterinary costs. It is assumed that the drylot was located on the ranch, therefore, no transportation costs were taken into account to transport calves to the drylot.

Statistical Analysis

Simulation results were not compared using typical statistical methods. Differences can be evaluated between the different replicates due to the stochastic nature of the MSU model (reproductive traits exhibit random variation, Tess and Kolstad, 2000a) as described by Julien and Tess (2002). However, the MARC model is deterministic and does not contain random elements, which means for a given set of inputs the output is always the same. In order to combine the results of the two models, the variation in mean ranch performance was reduced for the MSU model by performing thirty replications for each treatment where average results were utilized. Therefore, any test used for evaluating the variation is inappropriate due to a lack in variation inherent in the results.

Comparisons of the treatments was accomplished by ranking the treatments based on herd size, weaning weight per cow exposed (CWCE), purchased feed costs, average calf weaning weight (AWW), ranch gross margin (RGM), and cumulative gross margin (CGM).

CHAPTER NINE

OBJECTIVE TWO
EVALUATION OF DROUGHT MANAGEMENT STRATEGIES
RESULTS AND DISCUSSION

Results were evaluated based on herd size, average weaning weight, purchased feed cost, ranch gross margin, and cumulative gross margin. For each section, treatments using average forage quality will be discussed first and then discussion of drought forage quality will follow.

Herd Size

Herd size was sustained at the level determined by the base system under average climatic conditions (511 cows exposed to breeding). For all treatments herd size averaged at 511 cows and ranged from 505 to 516. The drought treatment was applied by reducing the available forage to simulate moderate drought (20% reduction) and severe drought (40% reduction). Feeding management decisions were made to sustain the herd size at the base system level by applying the two different management strategies. Hay price did not affect herd size.

During moderate drought, the normal management scenario included advancing the initiation of winter feeding to October 20th in order to sustain herd size and animal performance. The early management scenario, during the same drought, reduced the amount of feed needed to sustain herd size by eliminating all concentrate supplementation during the fall as well as maintaining the January 1st range removal date.

Table 33. Results of the base system and early management strategies, and profit/loss from the drylot component using **average** climatic conditions and **average** forage quality for both levels of hay cost

Item	Level of management	
	Base System	Early Management
Average Hay Cost		
Herd Size	511	516
AWW, kg	245	132
WWCE, kg	210	114
CWCE	86%	86%
Purchased Feed Cost	$13,911	-$11,889
Ranch Gross Margin	$137,055	$99,277
Drylot Component		
Total Purchased Feed Cost		$4,008
Cumulative Gross Margin		$145,840
High Hay Cost		
Herd Size	511	514
AWW, kg	245	132
WWCE, kg	211	115
CWCE	86%	87%
Purchased Feed Cost	$13,874	-$19,880
Ranch Gross Margin	$137,730	$107,364
Drylot Component		
Total Purchased Feed Cost		-$3,790
Cumulative Gross Margin		$154,393

AWW – average weaning weight
WWCE – weaning weight per cow exposed
CWCE – calves weaned per cow exposed
Ranch Gross Margin – gross margin less variable costs
Total Purchased Feed Cost – purchased feed costs plus feed costs of drylot component
Cumulative Gross Margin – ranch gross margin + revenue from drylot component

Table 34. Results of normal and early drought management strategies and profit/loss from the drylot component using **average** hay price and **average** forage quality

Item	Level of management	
	Normal Management	Early Management
Moderate Drought		
Herd Size	510	505
AWW, kg	245	133
WWCE, kg	210	115
CWCE	86%	86%
Purchased Feed Cost	$47,882	$15,566
Ranch Gross Margin	$102,026	$71,646
Drylot Component		
Total Purchased Feed Cost		$31,355
Cumulative Gross Margin		$117,091
Severe Drought		
Herd Size	509	511
AWW, kg	237	133
WWCE, kg	204	115
CWCE	86%	86%
Purchased Feed Cost	$87,801	$49,551
Ranch Gross Margin	$59,383	$38,856
Drylot Component		
Total Purchased Feed Cost		$65,451
Cumulative Gross Margin		$84,453

AWW – average weaning weight
WWCE – weaning weight per cow exposed
CWCE – calves weaned per cow exposed
Ranch Gross Margin – gross margin less variable costs
Total Purchased Feed Cost – purchased feed costs plus feed costs of drylot component
Cumulative Gross Margin – ranch gross margin + revenue from drylot component

Table 35. Results of normal and early drought management strategies and profit/loss from the drylot component using **high** hay price and **average** forage quality

Item	Level of management	
	Normal Management	Early Management
Moderate Drought		
Herd Size	510	505
AWW, kg	244	134
WWCE, kg	210	115
CWCE	86%	86%
Purchased Feed Cost	$59,015	$18,394
Ranch Gross Margin	$91,442	$68,954
Drylot Component		
Total Purchased Feed Cost		$35,252
Cumulative Gross Margin		$113,436
Severe Drought		
Herd Size	509	511
AWW, kg	235	134
WWCE, kg	202	115
CWCE	86%	86%
Purchased Feed Cost	$107,863	$62,349
Ranch Gross Margin	$38,131	$26,072
Drylot Component		
Total Purchased Feed Cost		$79,326
Cumulative Gross Margin		$70,578

AWW -- average weaning weight
WWCE – weaning weight per cow exposed
CWCE – calves weaned per cow exposed
Ranch Gross Margin – gross margin less variable costs
Total Purchased Feed Cost – purchased feed costs plus feed costs of drylot component
Cumulative Gross Margin – ranch gross margin + revenue from drylot component

Table 36. Results of normal and early drought management strategies and profit/loss from the drylot component using **average** hay price and **drought** forage quality

Item	Level of management	
	Normal Management	Early Management
Moderate Drought		
Herd Size	511	511
AWW, kg	237	133
WWCE, kg	203	114
CWCE	86%	86%
Purchased Feed Cost	$55,029	$32,044
Ranch Gross Margin	$90,373	$54,340
Drylot Component		
Total Purchased Feed Cost		$47,794
Cumulative Gross Margin		$100,050
Severe Drought		
Herd Size	511	515
AWW, kg	232	133
WWCE, kg	199	114
CWCE	86%	86%
Purchased Feed Cost	$91,853	$50,521
Ranch Gross Margin	$52,737	$36,604
Drylot Component		
Total Purchased Feed Cost		$66,380
Cumulative Gross Margin		$83,050

AWW – average weaning weight
WWCE – weaning weight per cow exposed
CWCE – calves weaned per cow exposed
Ranch Gross Margin – gross margin less variable costs
Total Purchased Feed Cost – purchased feed costs plus feed costs of drylot component
Cumulative Gross Margin – ranch gross margin + revenue from drylot component

Table 37. Results of normal and early drought management strategies and profit/loss from the drylot component using **high** hay price and **drought** forage quality

Item	Level of management	
	Normal Management	Early Management
Moderate Drought		
Herd Size	511	511
AWW, kg	237	133
WWCE, kg	204	115
CWCE	86%	86%
Purchased Feed Cost	$66,067	$39,301
Ranch Gross Margin	$80,924	$47,470
Drylot Component		
Total Purchased Feed Cost		$56,238
Cumulative Gross Margin		$92,350
Severe Drought		
Herd Size	511	514
AWW, kg	232	133
WWCE, kg	198	115
CWCE	86%	86%
Purchased Feed Cost	$113,688	$63,480
Ranch Gross Margin	$30,107	$23,474
Drylot Component		
Total Purchased Feed Cost		$80,292
Cumulative Gross Margin		$68,035

AWW -- average weaning weight
WWCE – weaning weight per cow exposed
CWCE – calves weaned per cow exposed
Ranch Gross Margin – gross margin less variable costs
Total Purchased Feed Cost – purchased feed costs plus feed costs of drylot component
Cumulative Gross Margin – ranch gross margin + revenue from drylot component

During severe drought, the normal management scenario advanced the winter feeding period to September 5th to maintain the cowherd. The increase in severity of drought caused the early management scenario to advance the winter feeding period to October 2nd to sustain a herd size of 511. Even though calves were early weaned this did not reduce the grazing pressure enough to maintain the winter feeding period of the base system during severe drought.

Altering forage quality posed a unique situation for maintaining herd size at 511. Due to lowering nutrient content in range forage, we supplemented the cows so much that some substitution of the forage was taking place and the model added more cows for 'extra' forage. Therefore, the model was altered to maintain constant herd size. All drought forage quality treatments had a herd size of 511 cows. The model is very sensitive to deficiencies in crude protein and altering the forage quality may be pushing the model to the boundaries of its usefulness.

Average Weaning Weight

Target average weaning weight was 245 kg for all normal weaning scenarios, which was the average weaning weight for the base system (table 33). During drought, when forage is limited and low in quality calf productivity may decline. Herbel et al. (1984) found that during drought weaning weights were significantly lower than found during normal climatic years. Drought reduced calf gain by 20% and adjusted weaning weights were 17% lower than found during average years in a study described by Bellido et al. (1981). Part of the reduction in calf gain results from the reduction in milk production after the 3rd mo of lactation (Neville, 1962; Robison et al., 1978) and also to reduced productivity of pastures (Burns et al., 1983). Drought limits the amount of forage available and reduces quality of forage. Cows cannot consume enough low quality forage to sustain milk production and calf gains suffer.

We found this to be true for normal management (NM) under several drought treatments. Since our goal was to maintain average weaning weights at 245 kg, those treatments that did not produce the target weights were subjected to two alternative supplementation strategies; mature lactating cows were given alfalfa hay as a replacement for grass/alfalfa hay in the fall, or an alfalfa creep feed was given to the calves. Tables 38 and 39 summarize the results for the treatments offered alternative supplementation strategies. Changing the supplementation strategies did increase the purchased feed costs, but the added feed increased weaning weights causing the RGM to increase more than the cost of the added feed. Creep feeding the calves increased RGM over that of feeding alfalfa hay to mature lactating cows and no change in supplement. Feeding alfalfa hay increased the RGM over not changing the supplement for NM under severe drought for both average and drought forage quality treatments, but not for moderate drought and drought forage quality. This was due to an increase in the number of days needed to supplement cows from 11 to 39d prior to weaning to cause an increase in the performance of calves.

Although there was an increase in RGM, NM did not have a greater gross margin than the early weaning strategies during drought. Since the supplementation options did not change ranks between levels of management, all subsequent results comparing treatments are reported without the additional gross margin gained from the supplementation options for the NM strategy.

For EM scenarios, the average weaning weight was 133 kg. Using the drylot component, the average target weights was 245 kg to match that of the normal weaned calves and were fed accordingly. It has been shown that early-weaned calves weigh as much or more at normal weaning than normal weaned calves during an average climatic year (Lusby et al., 1981; Neville and McCormick, 1981; Harvey and Burns, 1988; Myers et al., 1999a,b,c; Fluharty et al., 2000). Harvey et al. (1975) showed gains to be improved by approximately 0.30 kg/d when calves were early weaned compared with calves that remained on their dams. The performance of the early-weaned calves in the drylot was targeted at 245 kg to allow the management strategies to be directly comparable and not confounded by added income from heavier calves. The added efficiency of early-weaned calves has yet to be quantified, and breed, calving season, and region confound the results found from comparing performance of early weaned and normal weaned calves.

Table 38. Additional supplementation strategies for normal management to produce target weaning weights for **average** hay price

Item	Normal Management Severe Drought Average Forage Quality			Normal Management Moderate Drought Drought Forage Quality			Normal Management Severe Drought Drought Forage Quality		
Treatment	N	A	C	N	A	C	N	A	C
Weaning Weight, kg	237	250	244	237	245	243	232	249	246
Number of Days on Treatment		56	56		39	54		56	49
Total Purchased Feed Costs, $	87,801	86,877	77,339	55,029	69,346	57,101	91,853	95,005	84,582
Ranch Gross Margin, $	59,383	67,462	73,132	90,373	81,649	92,834	52,737	58,930	67,525

N – No change in supplement strategy from tables 22, 26, and 27
A – Alfalfa hay replaced grass/alfalfa hay for lactating cows during the fall
C – Ad lib access to alfalfa creep feed for calves

Table 39. Additional supplementation strategies for normal management to produce target weaning weights for **high** hay price

Item	Normal Management Severe Drought Average Forage Quality			Normal Management Moderate Drought Drought Forage Quality			Normal Management Severe Drought Drought Forage Quality		
Treatment	N	A	C	N	A	C	N	A	C
Weaning Weight, kg	235	250	243	237	245	244	232	249	246
Number of Days on Treatment		56	56		39	54		56	49
Total Purchased Feed Costs, $	107,863	110,674	96,018	66,067	85,655	67,448	113,688	118,476	103,572
Ranch Gross Margin, $	38,131	42,725	54,754	80,924	66,057	83,338	30,107	33,475	48,313

N – No change in supplement strategy from tables 22, 26, and 27
A – Alfalfa hay replaced grass/alfalfa hay for lactation cows during the fall
C – Ad lib access to alfalfa creep feed

Drylot Component for Early Weaned Calves

The early management treatment (EM) included weaning calves at an average 90d of age, culling dry cows at weaning and culling by age and nonpregnant cows 45 d after the end of breeding season to reduce grazing pressure on the stressed forage resource. The drylot component included feeding the early weaned calves to reach a target weight equivalent to that of normally weaned calves. During moderate drought and using average hay price, if calves were sold at weaning, RGM was roughly half of the base system and 67% less than that of NM (tables 33 and 34). For the same scenario, when the calves were placed in the drylot and the revenue from the heavier calves added to the RGM of EM, the base system still had a higher gross margin. The difference between EM during moderate drought and the base system during average climatic conditions was equal to the cost of feed for the calves in the drylot ($15,862, average feed cost for drylot utilizing average hay cost). However, during moderate drought, the CGM of EM was greater than that of NM by 13%. The changes in ranks between NM and EM scenarios were due to the increased income from additional weight of the calves placed in the drylot. Ranks between the profitability of NM and EM were the same during severe drought, high hay price, and drought forage quality (Refer to tables 33-36).

These results suggest that an early weaning option is not economically viable unless calves are kept and fed in a drylot. Story et al. (2000) supported these finding. They found that early-weaned calves did not weigh as much at weaning than normal weaned calves and even though price per unit of weight was greater for the lighter calves, there was not enough total money generated to offset the cow costs.

Level of Management

The question becomes whether it is more efficient and cost effective to feed cows at a level high enough to maintain lactation and preserve calf performance or to directly feed calves. Figures 13-16 show that for every climatic condition, hay price, and level of forage quality EM had higher returns than NM. This coincides with research done by Estermann et al. (2002) where they found it advantageous to put effort into supplementing calves rather than into improving milk yield of dams through better forage quality. Peterson et al. (1987) found that early weaned cow-calf pairs consumed 20.4% less TDN and were 43.0% more efficient in converting TDN into calf gain than normal weaned cow-calf pairs. Story et al. (2000) found that annual cow costs were lower for early-weaned cows than for those normal weaned.

With the drylot option, EM consistently had lower purchased feed costs and higher CGM than NM for both levels of drought, hay price, and forage quality. For average hay cost and average forage quality, NM total purchased feed cost was 35% and 25% greater than EM for moderate and severe drought, respectively. This is due primarily to maintaining herd size and performance, which required advancing the range removal date and increasing the total amount of feed needed.

Closely following the trends of purchased feed costs in drought was CGM for the simulated ranch where CGM for NM was lower than EM for both levels of drought, hay cost, and forage quality. For average hay cost, NM CGM was 13 and 30% lower than EM for moderate and severe drought, respectively. Again this is primarily due to the increases in feed costs for the NM strategy when drought occurs.

The same trends are seen in the treatments under the 'drought' forage quality where NM had higher total feed costs and lower CGM than EM but the differences between the two treatments were smaller.

Level of Drought

Intense drought greatly decreased the profitability of the cow-calf enterprises studied here. Under moderate drought, EM did well compared to the base system where the only difference in CGM was the $15,000 feed cost of the drylot calves for average forage quality. While EM had CGM consistently higher than NM (figures 13-16), the strategy alone did not reduce the grazing pressure enough to maintain gross margins comparable to the base system during severe drought. The NM CGM decreased as the intensity of drought increased.

Hay Cost

During drought, hay prices can increase due to reduced production and limited availability. Two levels of hay cost were used ($58.97/t grass, $68.04/t alfalfa vs. $77.11/t grass, $86.18/t alfalfa), but there was no change in the cost of other ration ingredients including concentrate supplements.

Hay price affected cost of purchased feed and CGM in proportion to the amount of hay used for each treatment, but did not change ranking of treatments. Increasing the hay cost, increased the total feed cost 19 and 11% for NM and EM when drought conditions were moderate. The changes in the total feed costs were reflected in the CGM for both NM and EM by decreasing the gross margin by 10 and 3% respectively. The same trends were seen during severe drought for both NM and EM. Purchased feed costs increased 19 and 17% for NM and EM. Gross margin decreased 36 and 16% for NM and EM, respectively.

Drought forage quality treatments followed the same trends where the rankings did not change between NM and EM. The differences were accentuated by the increase in hay price where there was a 15 and 20% increase in the differences between EM and NM for moderate and severe drought respectively.

Forage Quality

Forage quality may change in response to drought but there is little research quantifying the changes in animal diets. Research has shown that in individual plants nutrient concentration increases in response to drought (Sheafer et al., 1992; Nelson and Moser, 1994). However, with drought comes a decrease in yield (Reed and Peterson, 1961; Heitschmidt et al., 1999). Grazing animal diets are then composed of lower quality forages and forage parts than during a normal year. Therefore, the forage actually consumed by grazing animals will be lower in crude protein, metabolizable energy, and higher in NDF (Heitschmidt and Grings, personal communication). Forage quality curves were modified to reflect changes in cattle diets during drought (figures 10-12).

Differences between average and droughted forage quality did not change the rankings of the different management treatments, but drought forage quality did increase the feed costs and reduce the CGM for all treatments. Total purchased feed costs for NM and EM increased 15 and 52% for moderate drought and 5 and 1% for severe drought. Following the feed costs, CGM for NM and EM decreased 13 and 17% for moderate drought and 13 and 2% for severe drought. The relatively small change in total purchased feed costs and CGM for NM under severe drought was because the scenario needed no changes between the forage qualities. Both treatments for the severe drought did not change drastically because the supplementation period started early enough in the fall to thwart a major decrease in cow condition making large changes unnecessary. The only treatment that required large changes was EM during moderate drought. This scenario needed almost no supplementation prior to January 1st under average forage quality. Changing the forage quality required feeding a limited amount of grass/alfalfa hay beginning October 31st to maintain cow condition.

False Predictions of Drought

The incidences of false predictions of drought were low as described by Chapter 7. When the early management treatment was applied and no drought occurred, purchased feed costs decreased and CGM increased (table 33). The available forage during an average climatic year was enough for early-weaned cows to graze until April 1st, which allowed the ranch to sell the majority of home-raised hay. The total feed costs (including the drylot option) were only $4,007. This was a decrease of almost $10,000 from the base system. The CGM for EM under average climatic conditions was higher than the base system by 6% (figure 13). Feed costs for the drylot option would have to increase by 50% for EM to have the same breakeven cost of the base system.

When high hay price was added to the base system and early weaning scenario under average climatic conditions, EM increased CGM over the base system by another

$7,870. The increase in CGM for EM when using high hay cost is due to the ability of the scenario to sell the majority of the hay produced on the ranch.

Discussion

In this study we used computer simulation to address our objectives. Simulation models facilitate the integration of scientific concepts and experimental results into tools for addressing questions beyond the scope of live animal experimentation (Julien and Tess, 2002). Models are developed to represent important aspects of real systems based upon integrating a fountain of research. Still, models are only an abstraction of reality, and assumptions made and the boundaries of the model define what inferences can be made from the results. Our model simulated alternative management scenarios as existing ranches with all resources available. Additional costs that may be incurred by adjusting management such as additional facilities and labor were not included. In addition, the natural resource simulated did not include costs for improving pasture or range, which in the long term may lessen purchased feed costs if cattle gain more weight on summer pasture. We assumed that hay could be purchased as needed or sold if home-raised supply exceeded need. Due to this constraint our results for ranch gross margin are not easily compared to studies in which profit was measured on a per-cow basis (Julien and Tess, 2002).

We assumed that calving occurred in the spring and that all calf marketing occurred at the date of normal weaning. This represents many, but not all, ranches in the Northern Great Plains (Julien and Tess, 2002). These results should not be used to make inferences about other production/marketing systems, specifically, systems calving in different seasons.

Other drought management strategies that were not used in this study could forestall the economic effects on drought. We chose to constraint the possible management strategies to those that the model could simulate well and that producers would readily use. Animal performance was maintained for all treatments to reflect the need for cows to remain in good condition for rebreeding the next spring. Herd size was held constant because a reduction in herd size reduces the potential calf crop for subsequent years and producers tend to be reluctant to reduce cow numbers. Our results suggest that during severe drought maintaining herd size may not be economically profitable even if early weaning is employed.

Our results show that altering management early in the growing season by early weaning and feeding calves in a drylot had advantages over not altering management early for all levels of drought, hay price and forage quality. Most of the variation seen in cumulative gross margin between normal management and early management scenarios was reflected in the higher feed costs for the normal management scenario that was required to maintain animal performance and herd size. Feed cost is one of the most important variables that influence profit in a production system and is approximately 70% of the total cost of raising beef cows (Peterson et al., 1987). May et al. (1999) and Reisenauer (2001) noted that feed costs are highly related to weaning dates in studies evaluating season of calving.

There has been little research quantifying many aspects of drought and drought management making no studies directly comparable to this study. Peterson et al. (1987)

found that early weaning was more economical than normal weaning, but calves were born in the fall and no drought was observed. A study done by Mjelde and Hill (1999) evaluated several systems models describing the economic effects of climate forecasts on production of several crops. They found that the use of climate forecasts improved net income. There have also been several studies using our model to evaluate different management options. Reisenauer (2001) evaluated different seasons of calving, Julien and Tess (2002) evaluated the effects of breeding date, weaning date, and grazing season length on profitability, and Torstenson et al. (2002) evaluated elk management strategies and profitability of beef cattle ranches. These studies demonstrate the effectiveness of our model in evaluating different management strategies.

Early weaning may add flexibility in management to response to a changing environment. Our results suggest that if early weaning were done during an average climatic year, cumulative gross margin surpassed the base system. This has some limitations. In some regions, due to snow cover, it may not be possible to graze until early spring. Also, if producers were to employ this strategy all of the time, there would be no drought response possible except maybe to sell cows.

Implications

Based on the results discussed for cow-calf producers in the Northern Great Plains, an early management strategy, which includes early weaning and drylot feeding calves, can forestall the negative economic impacts of drought over that of merely supplementing cow-calf pairs. Level of drought and cost of purchased hay did not change the ranking of the strategies, but did accentuate the differences between the scenarios. Early weaning may not be an economically viable option unless calves are placed in a drylot and fed to a 'normal' weaning weight.

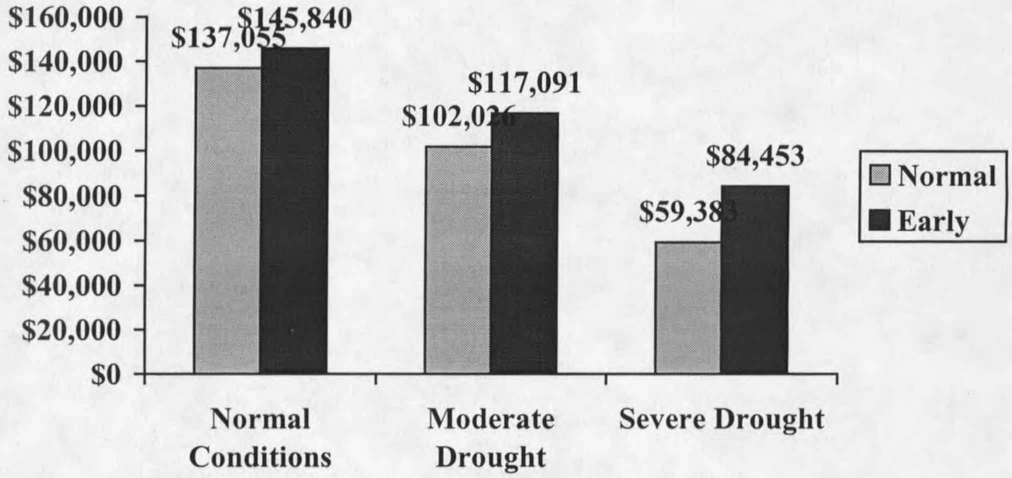


Figure 13. Cumulative gross margin for all treatments utilizing **average** hay price and **average** forage quality.

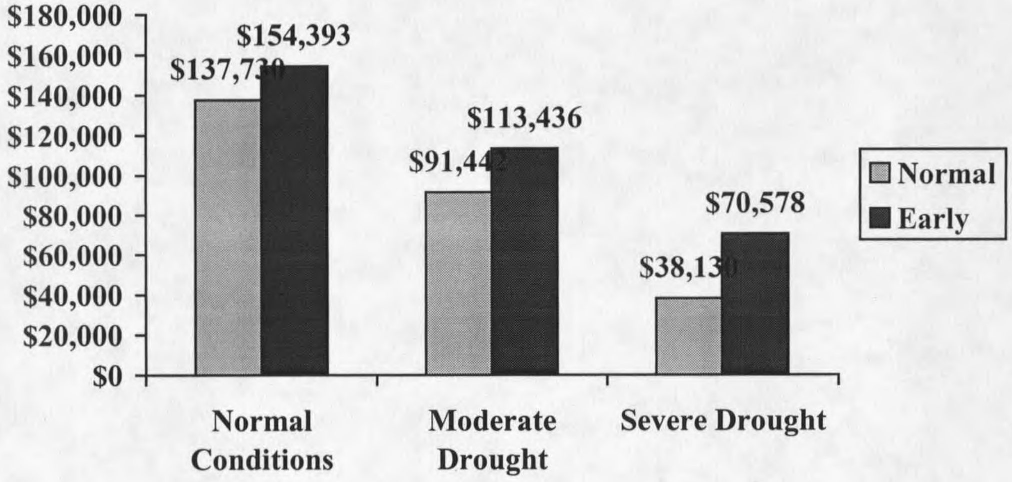


Figure 14. Cumulative gross margin for all treatments utilizing **high** hay price and **average** forage quality.

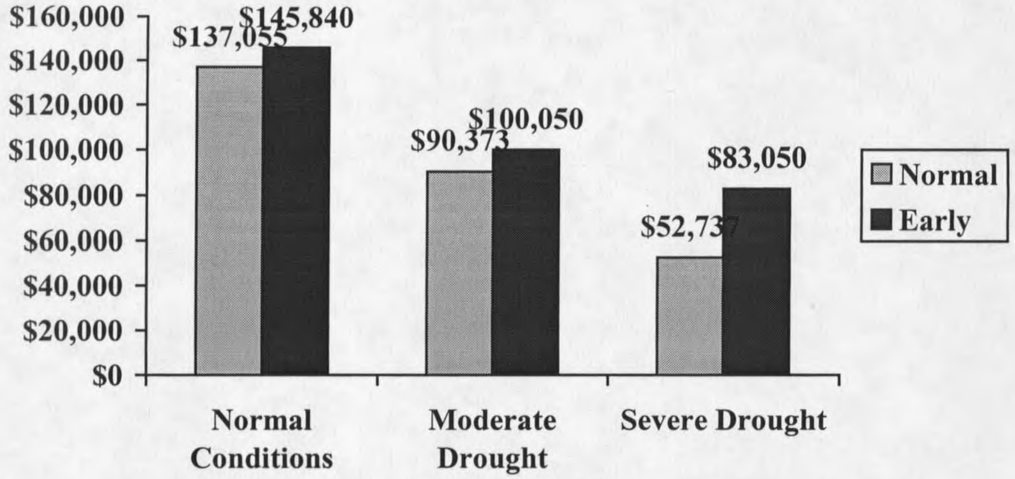


Figure 15. Cumulative gross margin for all treatments utilizing **average** hay price and **drought** forage quality.

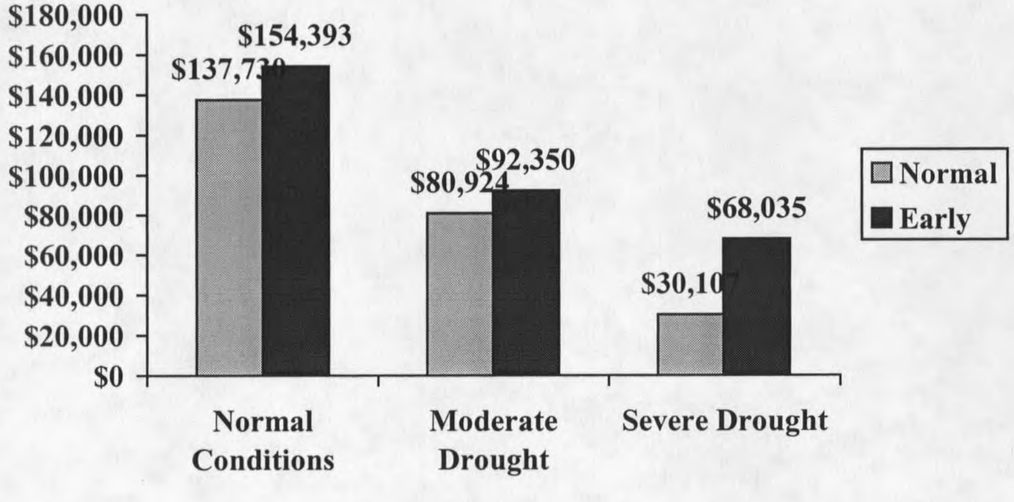


Figure 16. Cumulative gross margin for all treatments utilizing **high** hay price and **drought** forage quality.

CHAPTER TEN

CONCLUSIONS

Cow-calf producers tend to be overly optimistic, believing that the next day will bring much needed rain. This tends to decrease the flexibility to alter management in response to a changing environment. As drought emerges, early detection and management changes are one of the few methods available to producers to gain some measure of control over a variable environment.

Our results suggest that forage production can be predicted with some confidence from spring (April through June) precipitation. Our approach was to develop an early practical predictor to detect emerging drought. Although temperature variables and July precipitation added reliability to the models statistically, it decreased the usefulness as an early and/or practical predictor for cow-calf producers. Our results suggest that predictions based on spring precipitation could be used effectively to make management decisions as early as July 1st. Therefore, a lack in forage production by July 1st would indicate drought and a management response aimed at reducing grazing pressure could be made.

Our results also suggest that a drought management strategy, which includes early weaning and drylot feeding calves, can forestall the negative economic impacts of drought over that of merely supplementing cow-calf pairs. Differences in intensity of drought, cost of purchased hay, and changes in forage quality did not change the effectiveness of early weaning over normal management practices. Most of the variation seen in gross margins between normal management and early management strategies was reflected in the higher feed costs for normal management scenario. Directly feeding the calves proved to be more efficient than feeding the cows to produce milk to maintain calf performance. The reduction in nutrient requirements for cows early weaned substantially decreased the amount of feed compared to the normally weaned cows. However, during severe drought, early weaning calves did not reduce grazing pressure enough to maintain gross margins comparable to the base system. Additional management decisions may need to be made during a severe drought to remain economically profitable such as reducing herd size which was not looked at in this study.

Additional results suggest that false predictions of drought will not damage the cow-calf enterprise profitability. The early management strategy was simulated during an average climatic year and received gross margins that surpassed the ranch system under normal conditions. This is not possible for all producers because in this scenario cows could graze until April and in some regions snow cover inhibits this possibility.

It is also suggested that an early weaning strategy should not be used if calves are not placed in a drylot and fed to a 'normal' weaning weight. Even though price per unit of weight was greater for the lighter calves, there was not enough total money generated to offset the cow costs.

May it be noted that utilizing computer simulations to seek answers to large, complex questions has some limitations. Results gained should not be inferred beyond the boundaries of the model. Specifically, systems using different season of calving should not utilize these results.

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APPENDICES

APPENDIX A

SIMPLE CORRELATIONS FOR MILES CITY, MONTANA

Correlations between monthly **precipitation** totals and simulated forage yield index– Miles City, Montana

	Jan.[a]	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Index[b]
January	1	0.215	-0.192	0.013	0.069	0.249	-0.054	-0.285	-0.092	0.407*	0.180	0.200	0.304
February		1	-0.214	0.222	0.166	-0.014	0.026	-0.111	0.163	0.020	0.333	0.255	0.340
March			1	0.187	0.299	-0.154	-0.037	0.051	-0.167	0.008	-0.234	-0.110	0.295
April				1	-0.032	-0.024	-0.362*	-0.032	-0.186	-0.127	-0.196	0.264	0.624**
May					1	0.065	0.327	0.239	0.226	0.098	0.106	0.164	0.522**
June						1	-0.192	0.055	-0.342	0.367*	-0.051	-0.121	0.186
July							1	0.252	0.488**	0.107	0.302	0.091	-0.089
August								1	0.155	0.265	-0.023	-0.007	0.120
September									1	-0.219	0.346	0.203	0.071
October										1	-0.019	0.253	0.234
November											1	0.180	0.195
December												1	0.489**
Index													1

* P-value < 0.05

** P-value < 0.01

[a] Total monthly precipitation

[b] Forage Yield Index simulated output from Rangetek

Correlations between monthly average **maximum temperature** and simulated forage yield index– Miles City, Montana

	Jan.[a]	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Index[b]
January	1	0.659**	0.621**	0.482**	0.486**	0.372*	0.235	-0.309	-0.573**	-0.405*	-0.147	0.273	-0.042
February		1	0.682**	0.726**	0.595**	0.353	0.043	-0.308	-0.451*	-0.549**	-0.171	0.129	-0.149
March			1	0.746**	0.610**	0.527**	-0.107	-0.527**	-0.619**	-0.655**	-0.285	0.008	-0.055
April				1	0.707**	0.444*	-0.065	-0.428*	-0.490**	-0.634**	-0.166	0.168	-0.364*
May					1	0.522**	0.057	-0.540**	-0.554**	-0.681**	-0.290	0.072	-0.138
June						1	0.379*	-0.253	-0.331	-0.333	-0.170	0.112	-0.251
July							1	0.096	0.142	0.190	0.166	0.085	-0.365
August								1	0.551**	0.604**	0.365*	-0.179	-0.183
September									1	0.809**	0.539**	0.204	-0.314
October										1	0.495**	0.165	-0.148
November											1	0.370*	-0.340
December												1	-0.218
Index													1

* P-value < 0.05

** P-value < 0.01

[a] Average monthly maximum temperature

[b] Forage Yield Index simulated output from Rangetek

Correlations between monthly average **minimum temperature** and simulated forage yield index– Miles City, Montana

	Jan.[a]	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Index[b]
January	1	0.466*	0.455*	0.123	-0.113	-0.067	0.102	0.092	-0.053	0.208	0.064	0.274	-0.124
February		1	0.266	0.360	-0.068	0.105	0.192	0.433*	0.359*	0.076	0.078	0.085	-0.319
March			1	0.012	0.169	0.286	-0.293	0.060	0.035	-0.234	-0.103	-0.042	-0.120
April				1	0.458*	-0.011	0.148	0.120	0.190	0.248	0.084	-0.039	-0.331
May					1	0.276	0.037	-0.114	-0.191	-0.206	-0.009	0.102	-0.382*
June						1	-0.063	-0.088	-0.070	-0.409	-0.257	0.026	-0.198
July							1	-0.048	0.058	0.229	0.034	0.134	-0.414
August								1	0.269	-0.170	0.221	-0.276	-0.236
September									1	0.358	0.133	0.163	-0.070
October										1	0.119	0.038	0.148
November											1	0.081	0.137
December												1	-0.132
Index													1

* P-value < 0.05

** P-value < 0.01

[a] Average monthly maximum temperature

[b] Forage Yield Index simulated output from Rangetek

APPENDIX B

COMPARISON OF SIMPLE CORRELATIONS TO SMOLIAK (1986) FOR LETHBRIDGE, ALBERTA

Simple correlations between selected precipitation variables and forage production for Lethbridge, Alberta from Smoliak (1986) and this study for data collated to correspond to calendar year

	Correlation	
Variable	Smoliak (1986)	Kruse (2002)
April	0.40**	0.39**
May	0.46**	0.46**
June	0.42**	0.41**
July	0.41**	0.40**
August	0.12	0.11
September	0.26	0.28*
May + June	0.58**	0.58**
April through July	0.74**	0.76**
Previous Year through July	0.74**	0.71**
Previous September + April through July	0.77**	0.78**
Annual	0.74**	0.73**

* *P*-value < 0.05

** *P*-value < 0.01

APPENDIX C

SIMPLE CORRELATIONS FOR LETHBRIDGE, ALBERTA

Correlations between monthly **precipitation** totals and simulated forage yield index and actual forage data – Lethbridge, Alberta

	Jan.[a]	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Forage[b]	Index[c]
January	1	0.183	0.032	0.024	-0.038	-0.178	-0.115	-0.061	-0.185	-0.113	-0.175	0.228	0.007	0.002
February		1	0.114	0.300*	0.087	-0.231	0.158	0.062	0.073	0.074	0.256	0.223	0.330*	0.246
March			1	0.312*	0.113	0.092	-0.068	0.155	-0.188	0.137	-0.041	0.223	0.324*	-0.036
April				1	0.203	-0.197	0.150	0.277*	0.182	-0.280*	0.132	0.081	0.532**	0.532**
May					1	0.129	0.253	0.100	-0.036	-0.213	0.001	0.077	0.316*	0.109
June						1	-0.067	-0.085	-0.100	-0.022	-0.033	0.278*	0.389**	0.530**
July							1	0.136	0.286*	-0.172	-0.278*	-0.056	0.263	0.089
August								1	0.176	0.231	0.034	0.131	0.263	0.089
September									1	-0.145	0.192	-0.087	0.219	0.174
October										1	0.054	0.065	-0.157	-0.362*
November											1	0.076	0.010	0.012
December												1	0.285*	0.036
Forage													1	0.587**
Index														1

* P-value < 0.05

** P-value < 0.01

[a] Total monthly precipitation

[b] Forage is the forage production in kg/ha

[c] Index is the output from the RANGETEK model

Correlations between monthly average **maximum temperature** and simulated forage yield index– Lethbridge, Alberta

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Forage[b]	Index[c]
January	1	0.270	0.292*	0.138	0.082	-0.033	0.087	-0.147	0.056	-0.066	-0.158	0.352	-0.127	0.040
February		1	0.248	0.160	-0.119	-0.107	-0.203	0.075	0.037	-0.065	0.190	0.103	-0.033	-0.226
March			1	0.162	0.089	0.309	0.115	0.194	0.127	0.068	0.041	0.088	-0.340*	-0.295*
April				1	0.402**	0.075	-0.064	0.106	0.073	-0.141	-0.087	-0.130	-0.531**	-0.368**
May					1	0.112	0.216	0.027	0.123	-0.255	0.063	0.119	-0.404**	-0.399**
June						1	0.081	0.300*	0.056	-0.183	-0.163	-0.088	-0.435**	-0.254
July							1	-0.006	0.243	0.516	-0.215	0.243	-0.327*	-0.077
August								1	0.216	-0.002	0.172	-0.104	-0.365*	-0.261
September									1	0.117	0.217	0.245	-0.220	-0.206
October										1	-0.039	-0.015	0.154	0.255
November											1	0.212	0.017	0.095
December												1	-0.024	0.148
Forage													1	0.599**
Index														1

* P-value < 0.05

** P-value < 0.01

[a] Average monthly maximum temperature

[b] Forage is the forage production in kg/ha

[c] Forage Yield Index simulated output from Rangetek

Correlations between monthly average **minimum temperature** and simulated forage yield index– Lethbridge, Alberta

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Forage^{b}	Index^{c}
January	1	0.247	0.235	0.085	0.247	0.082	0.104	-0.130	0.165	0.082	-0.074	0.329*	-0.133	0.009
February		1	0.150	0.142	-0.290*	-0.106	-0.348*	0.057	-0.000	0.035	0.232	0.091	-0.083	-0.212
March			1	0.017	0.082	0.360*	0.044	0.238	0.024	0.130	0.152	0.088	-0.298*	-0.257
April				1	0.335*	0.042	-0.186	0.103	0.101	0.002	0.009	-0.132	-0.298*	-0.130
May					1	0.261	0.282*	-0.028	0.130	0.108	0.033	0.116	-0.337	-0.148
June						1	0.197	0.409	0.065	0.112	-0.089	0.069	-0.347*	-0.157
July							1	-0.202	0.148	0.365*	-0.061	0.404**	0.065	0.124
August								1	-0.106	-0.039	0.199	-0.130	-0.340**	-0.183
September									1	0.258	0.042	0.268	-0.037	-0.104
October										1	-0.040	0.127	0.067	0.037
November											1	0.164	-0.169	-0.072
December												1	-0.032	0.156
Forage													1	0.599**
Index														1

* P-value < 0.05

** P-value < 0.01

[a] Average monthly maximum temperature

[b] Forage is the forage production in kg/ha

[c] Forage Yield Index simulated output from Rangetek