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## A Stochastic Simulation Approach

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## ABSTRACT

Seasonal variability of steer production in southeastern Colorado was determined for low, moderate, and high stocking rates. The RANGES simulation model was calibrated and validated using nine years of historical weather data. Initial steer weight was established at 226.8 kg. Low, moderate, and high stocking rates were 5.6, 3.8, and 2.5 ha/steer. The 168-day grazing season was divided into six 28-day grazing periods. When rainfall and temperature were read from historical data, simulation results showed no significant differences ($p>.05$) between experimental and simulated live-weights for the six grazing periods. Simulated and experimental average daily gains were not significantly different ($p>.05$). When rainfall and temperature were treated as stochastic variables, final steer weights averaged 348.9, 347.0, and 342.6 kg under the low, moderate, and high stocking rates, respectively. Correspondingly, steer production was 21.8, 31.6, and 46.3 kg/ha, under the low, moderate, and high stocking rates, respectively. The probability of achieving a final steer weight within 355-365 kg was inversely related to stocking rate. The probability of achieving a lower final steer weight increased under the highest stocking rate. The probability distributions of final steer weight and seasonal animal production can be used as guidelines in assessing risks of achieving certain levels of steer production under continuous grazing.

# INTRODUCTION

The number of stocker operations is increasing in the Central Great Plains of the U.S. (Gee 1985). These operations consist of buying steer, or heifer calves at the beginning of the plant growing season (April-May) and selling them for feedlot finishing at the end of the plant growing season (September-October). The increase in the number of stocker operations, compared to cow-calf operations, has two possible explanations: 1) stocker operations are not as labor intensive as cow-calf operations, and 2) stocker operations adjust more easily to fluctuations in forage production and cattle prices. This flexibility allows the rancher to make adjustments in the livestock enterprise in response to environmental and marketing conditions.

Stocker operations face several types of risks. Among these, market and production risk are considered the most important. Cattle prices change with time and cattle weight. Forage supply changes with temperature and rainfall conditions. At the beginning of the grazing season, available forage may be sufficient to start grazing but cattle prices may be relatively high. In contrast, cattle prices may be low but the standing forage may not be sufficient to meet daily cattle requirements. Market price and availability of forage may influence the decision-making process toward the end of the grazing season also.

A significant component of production risk is the fluctuation of rainfall and its effect on forage supply. This fluctuation affects forage production and influences animal performance. Sims and Singh (1978) found that precipitation, during the current growing season, accounted for 73 percent of the variability of forage production in southeastern Colorado. Once the stocker operation has started, adjustments in stocking rates may be necessary to compensate for changes in the quality and quantity of the forage, and for fluctuations in livestock market prices.

Associated probabilities of achieving, or failing to achieve, different targets of steer production are fundamental components of risk analysis (Walker and Helmers 1983, and Tharel et al. 1986). Expected values of seasonal animal production are often used to compare different treatments (e.g., stocking rate). These expected values usually assume the same weight to over- and under-estimations of the same magnitude.

As a preliminary step in assessing risk production of stocker operations, this study used simulation in determining the influence of rainfall fluctuation on forage growth and livestock production in southeastern Colorado. Specifically, warm season grasses, cool season grasses, and daily steer growth, all subjected to stochastic rainfall and temperature conditions, were determined for three different stocking rates under continuous grazing.

## MODELLING RANGELAND LIVESTOCK PRODUCTION AND RISK ANALYSIS

Several models have been developed to simulate the growth of cattle under rangeland conditions (e.g. Rice et al. 1974, Anway 1978, Sanders and Cartwright 1979, Brorsen et al. 1983, Swift 1983, Spreen et al. 1985, Loewer and Smith 1986, among others). These models require external input of forage quality information for different types of pastures. As a consequence, the variability in the results from these models depends on the variability in forage production. Moreover, they assume average seasonal variability in forage quality, but do not take into account the relationship between forage quality, plant growth, or plant phenology.

Risk analysis of cattle production in rangelands has been researched by some authors. Kothmann and Smith (1983) used the model developed by Sanders and Cartwright (1979) to evaluate management strategies in Texas under variable annual weather. Beck et al. (1982) modeled the financial and production risk effect of weather variability on pasture improvements in New South Wales, Australia. The authors used a mechanistic procedure to determine forage and animal production. Hamilton et al. (1986) used different levels of precipitation to evaluate the profits from variable forage production under two different brush spraying treatments. None of these studies considered the intra-seasonal variation in precipitation, and its influence on forage quantity and quality dynamics. Instead, rainfall and its effect on forage and livestock production were considered on an annual basis.

The intra-seasonal variation of forage production was taken into account in the study done by Parsch et al. (1986). The authors used the Kentucky beef-forage model (Loewer and Smith 1986) to derive probability distributions of animal production per head, and per unit of area. They also estimated net return per area across various management strategies. Stochastic dynamic programming was used to study rainfall risk of stocker operations in northeastern Colorado (Rodríguez and Jameson 1988). The authors concluded that, under low stocking rates, the stochastic system can be managed as a deterministic one. Under high stocking rates, the intra-seasonal forage variability needs to be taken into account if poor animal performance and range over-utilization are to be avoided.

## MATERIALS AND METHODS

### The Site

The Southeastern Colorado Research Center (SECRC) is located approximately 15 km west of Springfield, Colorado, in Baca County, 37° 23' north latitude and 102° 44' west longitude. Average elevation is 1396 m above sea level. Average annual precipitation at SECRC is 385 mm over a 23-year period (Peel 1986). Average monthly temperatures range from a minimum of 0°C in January to a maximum of 24°C in July (Peel 1986). Soils at the study site are mostly composed of the Campo clay loam series.

These soils are characterized as deep, nearly-level, moderately-dark-colored clay loams with slow permeability and high water holding capacities (Woodyard et al. 1973). According to Woodyard et al. (1973), blue grama (*Bouteloua gracilis* (H.B.K.)) and buffalograss (*Buchloe dactyloides* (Nutt. Engelm.)) are the dominant warm season grasses. Six-week fescue (*Vulpia octoflora* (Walt)), squirreltail (*Sitanion hystrix* (Nutt.) J.G. Smith), and western wheatgrass (*Agropyron smithii* Rye.) are the most important cool season grasses.

### The RANGES model

A series of grassland ecological sub-models were combined under the title RANGES (Gilbert 1975). The RANGES model uses available information regarding the growth of herbage in a grassland ecosystem as a function of the major driving variables, temperature and rainfall. The soil water sub-model takes temperature and rainfall as inputs and, after accounting for evapotranspiration, yields available soil water.

The plant growth sub-model calculates basic photosynthesis and respiration rates as functions of soil water and temperature. This information is then used to calculate potential plant production per unit of live plant material. Plants are divided into cool season (C3) and warm season (C4) grasses. Their proportion can be calibrated according to the site. Death and decay of green material are incorporated in the plant growth sub-model as a function of respiration, temperature, soil water, and intensity of grazing.

A consumer sub-model controls plant growth as a function of the number of animals present. Control is attributed not only to grazing but also to trampling losses. The model is designed to handle several livestock classes. The consumers's diet is composed of live and dead material. Ingestion rate is determined by simulating rumen activity (Rice et al. 1974). Rumen capacity is determined as a constant proportion of the metabolic size of the animal. The potential ingestion rate is the rumen capacity minus the rumen fill, which is composed of rumen dry matter and microbial protein.

Dietary nitrogen content is used as an index to organic matter digestibility. The amount of nitrogen in the forage is determined by the relative rate of plant growth. One hundred grams of digestible organic matter is equivalent to 430 kcal of energy. If microbial protein yield is 8 g/g of digestible organic matter, .0186 g of protein is produced per kcal digestible organic matter. As nitrogen in the diet increases, digestibility and growth of microbial protein increases. However, when dietary nitrogen content exceeds 1.8% microbial protein, growth is assumed to hold constant. Rumen microbial protein content determines how much of the potentially digestible food will be digested. As microbial protein increases, the fermentation digestion rate increases, which increases the exit rate of digestible material. Higher fermentation rates add to the normal passage rate of material from the rumen to the intestine, increasing potential intake.

Weight gain for each livestock class is determined by subtracting metabolic requirements from the energy resulting from digestion. Energy is obtained from food passed into the intestine, from microprotein, and from volatile fatty acids produced in the rumen. Livestock respiration, excretion and all animal losses are assumed to be the difference between total food ingested and weight gain.

## Procedures

The study consisted of two major components: 1) calibration and validation of the RANGES model in predicting steer production using historical temperature and precipitation, and 2) a stochastic simulation of two hundred years of steer production for three different stocking rates using temperature generated by a sine function, and rainfall generated using the gamma function.

### Model validation.

Daily precipitation, and minimum and maximum daily temperatures from 1969 to 1977, were input into the RANGES model. With the purpose of verifying the accuracy of the model in predicting live-weight gain, the simulated results were compared to the experimental gains reported by Cook and Rittenhouse (1988). Simulations for each of the nine years were done assuming the same initial condition for soil parameters, standing dead forage, number of animals, and beginning or ending date of grazing. On May 1, 50 227 kg steers calves were placed in a 190-ha pasture (i.e. 3.8 ha/steer) for 168 days. The grazing season was divided into six 28-day periods. The time-step of the simulation model was one day.

**Stochastic simulations of grazing seasons at SECRC.**

The stochastic simulations of steer weights were obtained by providing the RANGES model with stochastic temperature and rainfall. The stochastic rainfall generator was an adaptation of the one used by Bond (1979). Daily rainfall occurrence was assumed to have a first-order Markovian property. This means that the probability of measurable precipitation occurrence depended only on whether the preceding day was dry or wet.

A wet day was defined as any day with more than, or equal to .13 mm of precipitation. The probability of a wet day i, given that the previous day i-1 was wet ($P_i(W|W)$), is expressed as

$$P_i(W|W) = 1 - P_i(D|W)$$

where $P_i(D|W)$ is the probability of day i being dry, given that the day i-1 was wet. The probability of a wet day i, given that the previous day (i-1) was dry ($P_i(W|D)$), is

$$P_i(W|D) = 1 - P_i(D|D)$$

where $P_i(D|D)$ is the probability of a dry day i given that the previous day was also dry. The sequence of dry and wet days is described by the probabilities $P_i(W|W)$, $P_i(W|D)$, and the presence of a wet or dry day in the previous day (Richardson

1981). Rainfall intensities on wet days were assigned using two two-parameter gamma distributions estimated for every month. The two-parameter gamma distribution $f_k(x)$ is defined as:

$$f_k(x) = \frac{1}{\beta(k)^{\alpha(k)}\,\Gamma\,\alpha(k)}\; x^{\alpha(k)-1}\, e^{-x/\beta(k)};$$

$$\text{for}\quad \alpha>0,\ \beta>0,\ \text{and } k = 1,2$$

where x is the random variable, $\beta(k)$ is the scale parameter on x, $\alpha(k)$ is the shape parameter, $\Gamma$ is the usual gamma function, and $f_k(x)=0$ for $x<0$. The parameters $\alpha$ and $\beta$ for every month of the year shown in Table 1 were calculated by the method of maximum likelihood estimator according to Bury (1975). The index k=1 implies that a wet day occurred the previous day, while k=2 implies that a dry day occurred the previous day. The same sequence of random numbers was used to simulate rainfall events for each stocking rate. Table 2 shows the accumulated rainfall averages and their standard deviations for the period 1957-1982, and for the 200-years of stochastically generated rainfall.

Daily temperature was simulated with a sine function representation of historical averages calibrated to SECRC conditions by Rodriguez et al.(1987). Steer weight, soil characteristics, beginning and ending date of the growing season, and green biomass present were reset to the same initial values for every year of the simulation run. Each set of 200 simulations was done for low, moderate, and high (5.6, 3.8, and 2.5 ha/steer, respectively) stocking rates.

**Table 1. Monthly probabilities of rainfall occurrences and coefficients of the two two-parameter gamma distributions for rainfall events at SECRC[1].**

| MONTH | $P_i(W\|D)$ | $P_i(W\|W)$ | $k^1=1$ | | k=2 | |
|---|---|---|---|---|---|---|
| | | | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ |
| January | .093 | .298 | 1.11 | 1.63 | .92 | 3.03 |
| February | .111 | .253 | .81 | 4.34 | 1.05 | 2.24 |
| March | .140 | .350 | .68 | 5.96 | .89 | 4.99 |
| April | .132 | .338 | .87 | 7.22 | .68 | 11.11 |
| May | .221 | .450 | .74 | 11.24 | .66 | 10.53 |
| June | .164 | .462 | .73 | 11.11 | .75 | 9.05 |
| July | .262 | .341 | .70 | 9.83 | .84 | 8.75 |
| August | .184 | .361 | .59 | 14.90 | .80 | 7.33 |
| September | .129 | .354 | .80 | 6.45 | .74 | 7.90 |
| October | .087 | .361 | .79 | 6.73 | .73 | 7.37 |
| November | .092 | .357 | .72 | 5.91 | 1.04 | 4.64 |
| December | .085 | .315 | .96 | 2.68 | .88 | 3.18 |

1 Daily weather data (1957-1982) were used for the estimation of these parameters.

2 The index k defines the specific distribution for those wet days with a wet or dry previous day (k=1 or 2, respectively).

**Table 2. Comparison between the historically (1957-1982) and the stochastically generated 200-year rainfall averages.**

| GRAZING PERIOD | JULIAN DAY | HISTORICAL MEAN[1] (mm) | STD (mm) | GENERATED MEAN[2] (mm) | STD[3] (mm) |
|---|---|---|---|---|---|
| | 120 | 72 | 45 | 77 | 30 |
| 1 | | | | | |
| | 148 | 127 | 71 | 142 | 47 |
| 2 | | | | | |
| | 176 | 189 | 71 | 192 | 60 |
| 3 | | | | | |
| | 204 | 237 | 76 | 244 | 64 |
| 4 | | | | | |
| | 232 | 292 | 82 | 296 | 74 |
| 5 | | | | | |
| | 260 | 319 | 86 | 327 | 78 |
| 6 | | | | | |
| | 288 | 344 | 90 | 347 | 80 |

[1] Accumulated mm of rainfall up to the specified Julian day. Average of 26 historical years.

[2] Accumulated mm of rainfall up to the specified Julian day. Average of 200 simulated years.

[3] Standard deviation

# RESULTS AND DISCUSSION

## Model validation

### Changes in green forage.

Table 3 shows the nine-year averages of green biomass production under moderate stocking rate (3.8 kg/ha). The biomass of cool season grasses (C3) increased from 7.3 $g/m^2$ at the beginning of the first grazing period, to 9.1 $g/m^2$ at the end of the second grazing period. By the end of the grazing season, average C3 green biomass decreased to 5.1 $g/m^2$. Green warm season (C4) grasses had slow growth at the beginning of the grazing season. They increased from 2.3 $g/m^2$ at the beginning of the first grazing period, to 146.7 $g/m^2$ at the end of the fifth grazing period. Average C4 green biomass declined to 144.5 $g/m^2$ at the end of the grazing season.

Lack of data on seasonal forage production impeded the validation of the green biomass production results for every period of the grazing season. The simulated caged final standing crop 1969-1977 average, calculated as amount of C3 plus C4 green biomass, was 181.8 $g/m^2$ with an standard deviation of 74.6 $g/m^2$. This average was 18 percent higher than the 153 $g/m^2$, reported by Cook and Rittenhouse (1988). Paired t-test between the experimental final standing crops from 1969 through 1977, and the end of the season accumulated biomass generated by RANGES, did not show significant differences ($p>.05$). The largest over-estimation in C3 plus C4 biomass occurred in 1977, while the largest under-estimation occurred in 1974.

**Table 3. Summary of historically simulated C4 and C3 green biomass 1969-1977 averages, under a moderate stocking rate at SECRC.**

| END OF GRAZING PERIOD | JULIAN DAY | GRASSES[1] C4 (g/m$^2$) | C3 | CUM.[2] PPT (mm) | |
|---|---|---|---|---|---|
| | 120 | 2.3 | 7.3 | 93 | MEAN |
| | | .5 | 3.2 | 47 | STD[3] |
| 1 | 148 | 7.3 | 8.6 | 152 | MEAN |
| | | 4.4 | 3.6 | 88 | STD |
| 2 | 176 | 52.3 | 9.1 | 216 | MEAN |
| | | 40.5 | 4.1 | 76 | STD |
| 3 | 204 | 100.2 | 5.0 | 257 | MEAN |
| | | 60.1 | 5.0 | 89 | STD |
| 4 | 232 | 130.7 | 6.2 | 316 | MEAN |
| | | 64.0 | 4.9 | 93 | STD |
| 5 | 260 | 146.7 | 4.1 | 344 | MEAN |
| | | 66.1 | 5.2 | 102 | STD |
| 6 | 288 | 144.5 | 5.1 | 379 | MEAN |
| | | 67.3 | 5.1 | 104 | STD |

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1 Green biomass

2 CUM. PPT. = 1969-1977 cumulative precipitation average

3 STD = standard deviation

<u>Changes in animal weight.</u>

Table 4 shows the experimental and simulated live-weights nine-year averages for the six grazing periods. T-tests did not show statistical differences ($p>.05$) between the experimental and simulated nine-year averages for any of the six grazing seasons. In spite of higher values of standard deviations in the first and second grazing periods, F-tests for homogeneity of variance did not show significant differences ($p>.05$) between the simulated and experimental variances for any of the grazing periods. Figure 1a shows the comparison between experimental and simulated steer weights from 1969 through 1977. The largest differences in steer weight occurred in 1974 for the first, second, third, and fourth period, and in 1972 for the fifth and sixth period. Final experimental and simulated nine-year averages were 346.4 and 346.5, respectively.

The seasonal nine-year average daily gain of both experimental and simulated trails was .71 kg/day. Both, the highest experimental (.88 kg/day) and simulated (.90 kg/day) average daily gain occurred in the third grazing period (Table 4). Both the lowest experimental (.43 kg/day) and simulated (.45 kg/day) average daily gain occurred in the sixth grazing period. The largest difference in average daily gain occurred in the first grazing period. However, paired t-tests between the 1969-1977 simulated and experimental average daily gains did not show significant differences ($p>.05$) for any of the grazing periods. Figure 1b shows the simulated and experimental seasonal average daily gains from 1969 through 1977.

**Table 4. Summary of the experimental and historically simulated 1969-1977 live-weight averages, and the corresponding average daily gains at SECRC.**

| END OF GRAZING PERIOD | JULIAN DAY | LIVE-WEIGHT AND AVERAGE DAILY GAIN EXPERIMENTAL (kg) | (kg/day) | SIMULATED (kg) | (kg/day) | |
|---|---|---|---|---|---|---|
| | 120 | 226.8 | --- | 226.8 | --- | MEAN |
| | | --- | --- | --- | --- | STD[1] |
| 1 | 148 | 248.8 | .79 | 246.6 | .71 | MEAN |
| | | 1.9 | .07 | 3.5 | .12 | STD |
| 2 | 176 | 270.7 | .78 | 268.5 | .78 | MEAN |
| | | 5.0 | .15 | 7.6 | .16 | STD |
| 3 | 204 | 295.3 | .88 | 293.6 | .90 | MEAN |
| | | 9.6 | .25 | 10.0 | .15 | STD |
| 4 | 232 | 315.3 | .71 | 314.1 | .73 | MEAN |
| | | 10.1 | .19 | 13.8 | .16 | STD |
| 5 | 260 | 334.3 | .68 | 333.8 | .70 | MEAN |
| | | 13.5 | .30 | 14.7 | .04 | STD |
| 6 | 288 | 346.4 | .45 | 346.5 | .43 | MEAN |
| | | 14.0 | .17 | 15.3 | .03 | STD |

[1] STD = standard deviation

Figure 1a. Experimental and simulated steer weight for six grazing periods from 1969 through 1977.

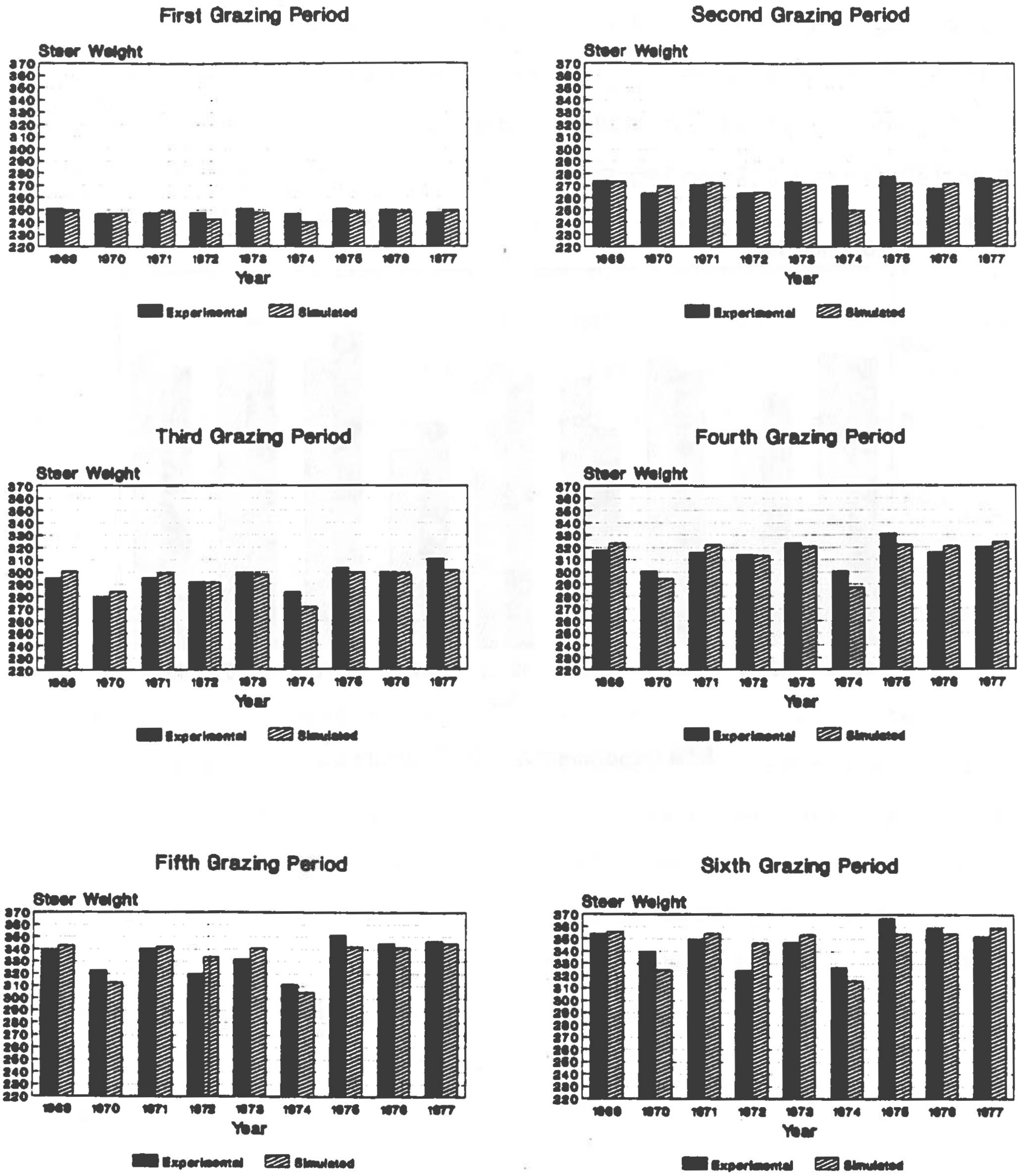
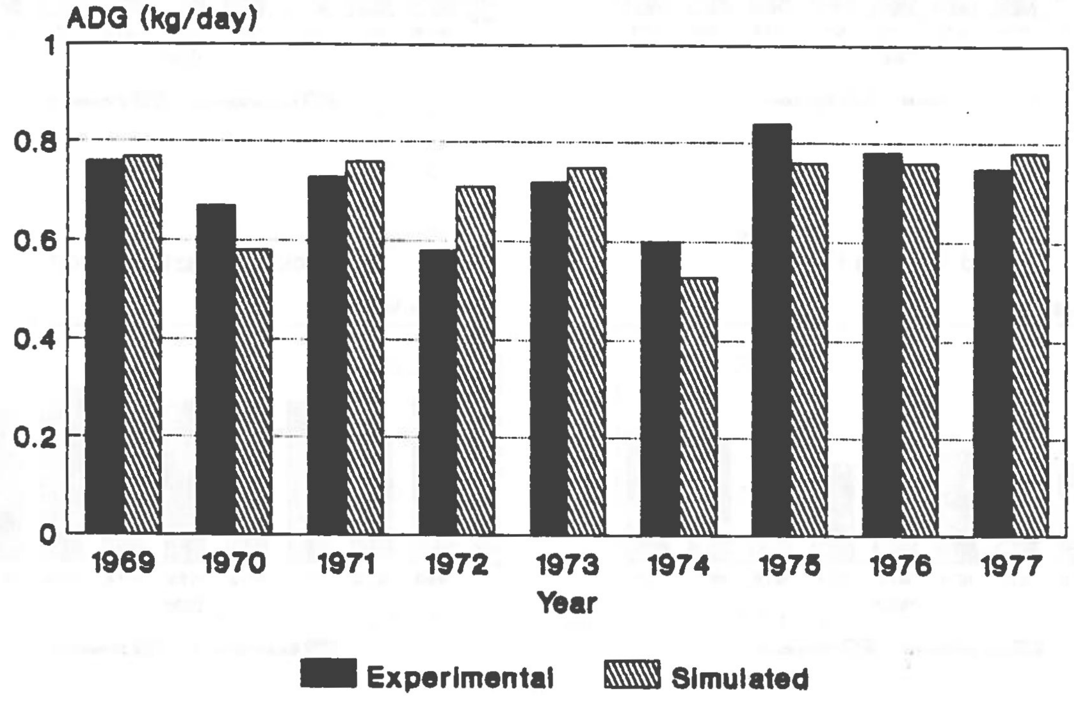


Figure 1b. Experimental and simulated seasonal average daily gains from 1969 through 1977.



### Stochastic simulations

Changes in green forage.

The green biomass of C4 and C3 grasses, for the moderate stocking rate, followed a similar trend throughout the grazing season, when compared to the nine-year averages derived from the historical simulation. The C3 green biomass production (Table 5) reached its maximum at the end of the first grazing period for all stocking rates considered. Increasing the stocking rate from low to high caused a 11 percent decrease in the availability of C3 green biomass in the period of maximum growth. The C4 green biomass production (Table 5) reached its maximum at the end of the sixth grazing period for the low and moderate stocking rate, and at the end of the fifth grazing period for the high stocking rate. Increasing the stocking rate from low to high caused a 20 percent decrease in the availability of C4 green biomass in the period of maximum growth.

When RANGES was run with no animals present, no significant differences were found between the historically simulated (181.8 ±74.61), the stochastically simulated (162.1 ±70.7), or the experimental (153 ±38.1) nine-year-average final standing crops. Nevertheless, the standard deviation of the experimental nine-year average standing crop was significantly lower (85 percent) than the standard deviation of the historically simulated and stochastically simulated standing crop. Unfortunately, the lack of experimental green biomass information impeded the analysis of the differences between experimental and simulated results for every period of the grazing season.

**Table 5. Summary of two hundred-year stochastically simulated green biomass at SECRC for low, moderate, and high stocking rate.**

| | | STOCKING RATE | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | LOW[1] | | MODERATE[2] | | HIGH[3] | | |
| END OF GRAZING PERIOD | JULIAN DAY | C4 | C3 | C4 (g/m²) | C3 | C4 | C3 | |
| | 120 | 1.3 | 7.3 | 1.3 | 7.3 | 1.3 | 7.3 | MEAN |
| 1 | | .1 | 3.3 | .1 | 3.3 | .1 | 3.3 | STD[4] |
| | 148 | 6.7 | 10.3 | 6.1 | 9.7 | 5.3 | 9.2 | MEAN |
| 2 | | 1.6 | 2.7 | 1.6 | 2.6 | 1.5 | 2.7 | STD |
| | 176 | 59.2 | 9.2 | 52.9 | 8.3 | 43.4 | 7.6 | MEAN |
| 3 | | 23.4 | 3.6 | 21.9 | 3.3 | 19.7 | 3.3 | STD |
| | 204 | 113.4 | 4.8 | 108.5 | 3.7 | 100.3 | 3.2 | MEAN |
| 4 | | 40.5 | 4.1 | 42.4 | 3.7 | 45.9 | 3.4 | STD |
| | 232 | 131.3 | 1.0 | 124.6 | .9 | 113.3 | .8 | MEAN |
| 5 | | 45.1 | 1.9 | 46.1 | 1.7 | 50.7 | 1.5 | STD |
| | 260 | 136.8 | .7 | 129.0 | .6 | 115.6 | .6 | MEAN |
| 6 | | 58.6 | 2.1 | 58.1 | 1.9 | 59.7 | 1.6 | STD |
| | 288 | 140.5 | .7 | 130.1 | .6 | 114.0 | .6 | MEAN |
| | | 66.1 | 2.1 | 65.2 | 2.0 | 65.6 | 1.8 | STD |

1 LOW = 5.6 ha/steer during 168 days

2 MODERATE = 3.8 ha/steer during 168 days

3 HIGH = 2.5 ha/steer during 168 days

4 STD = standard deviation

## Changes in animal weight

Table 6 summarizes the results of stochastically simulated two hundred-year average steer weights for three different stocking rates. The average steer weight was highest for the low stocking rate, followed by the moderate, and the high stocking rate (Figure 2a). In contrast, the coefficient of variation (Figure 2b) of steer live-weight was largest for the high stocking rate. The final simulated average steer weights were 348.9, 347.0 and 342.6 kg for the low, moderate, and high stocking rates respectively. These were equivalent to 122.1, 120.2, and 115.8 kg/steer of seasonal gain, or 21.8, 31.6, and 46.3 kg/ha of seasonal animal production under low, medium, and high stocking rate, respectively.

Stochastically simulated average daily gains followed the same trend as the historically simulated ones (Figure 3a). When the intra-seasonal average daily gains are considered, the maximum average daily gain (Figure 3b) was reached at the end of the third grazing period for all stocking rates (.94, .93 and .89 kg/day for low, moderate, and high, respectively). The minimum average daily gain was observed to occur in the last grazing period for all stocking rates. The stochastically simulated season-long average daily gain for the moderate stocking rate (.72 kg/day) was not significantly different ($p>.05$) than the historically simulated (.71 kg/day) season-long average daily gain. The stochastically simulated season-long average daily gains for the low and high stocking rates were .73 and .69 kg/day, respectively.

**Table 6. Summary of stochastically simulated two hundred-year average steer weight at SECRC for three different stocking rates.**

| END OF GRAZING PERIOD | JULIAN DAY | STOCKING RATE | | | CUM.[4] PPT. (mm) | |
|---|---|---|---|---|---|---|
| | | LOW[1] | MODERATE[2] | HIGH[3] | | |
| | | STEER WEIGHT (KG) | | | | |
| | 120 | 226.8 | 226.8 | 226.8 | 77 | MEAN |
| 1 | | ------ | ------ | ------ | 30 | STD[5] |
| | 148 | 246.8 | 246.6 | 246.3 | 142 | MEAN |
| 2 | | 2.6 | 2.7 | 3.0 | 47 | STD |
| | 176 | 269.7 | 269.2 | 268.2 | 192 | MEAN |
| 3 | | 5.1 | 5.8 | 7.2 | 60 | STD |
| | 204 | 296.1 | 295.1 | 293.1 | 244 | MEAN |
| 4 | | 7.2 | 8.8 | 12.4 | 64 | STD |
| | 232 | 318.0 | 316.7 | 313.7 | 296 | MEAN |
| 5 | | 9.4 | 11.9 | 17.3 | 74 | STD |
| | 260 | 336.9 | 335.3 | 331.6 | 327 | MEAN |
| 6 | | 11.3 | 15.0 | 21.9 | 78 | STD |
| | 288 | 348.9 | 347.0 | 342.6 | 347 | MEAN |
| | | 13.1 | 17.4 | 25.7 | 80 | STD |

1 LOW = 5.6 ha/steer during 168 days

2 MODERATE = 3.8 ha/steer during 168 days

3 HIGH = 2.5 ha/steer during 168 days

4 CUM. PPT. = cumulative precipitation.

5 STD = standard deviation.

Figure 2a. Stochastically simulated 200-hundred year average steer weight for three stocking rates (2.5, 3.8, and 5.6 ha/steer for high, moderate, and low respectively).

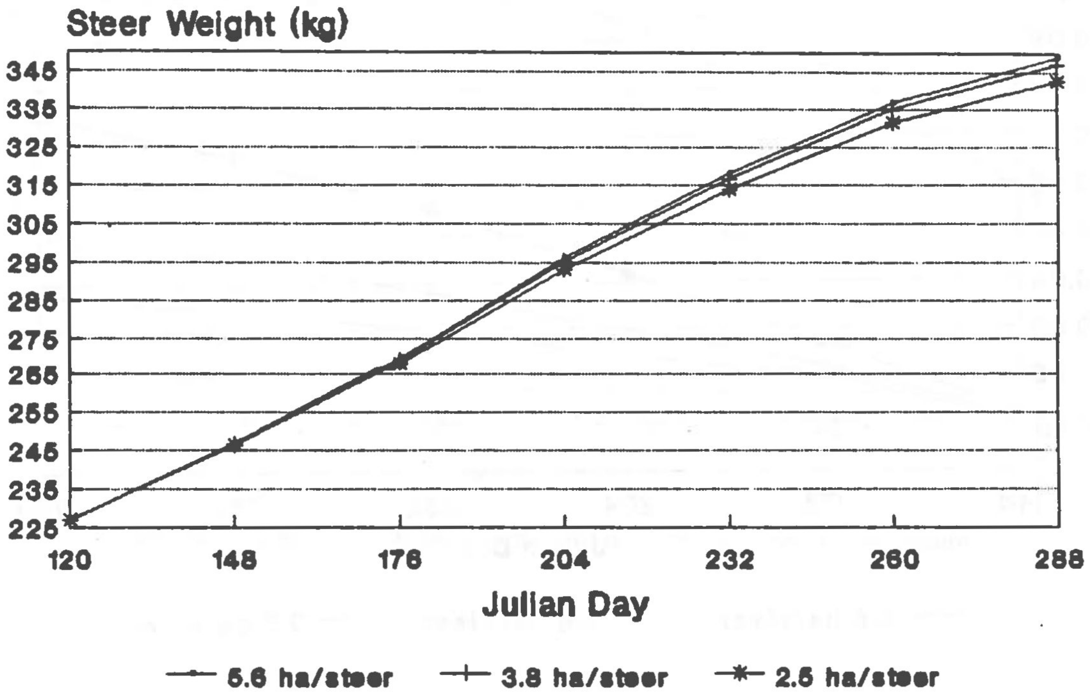


Figure 2b. Coefficients of variation of seasonal steer weight for six grazing periods and three stocking rates (2.5, 3.8, and 5.6 ha/steer for high, moderate, and low respectively).

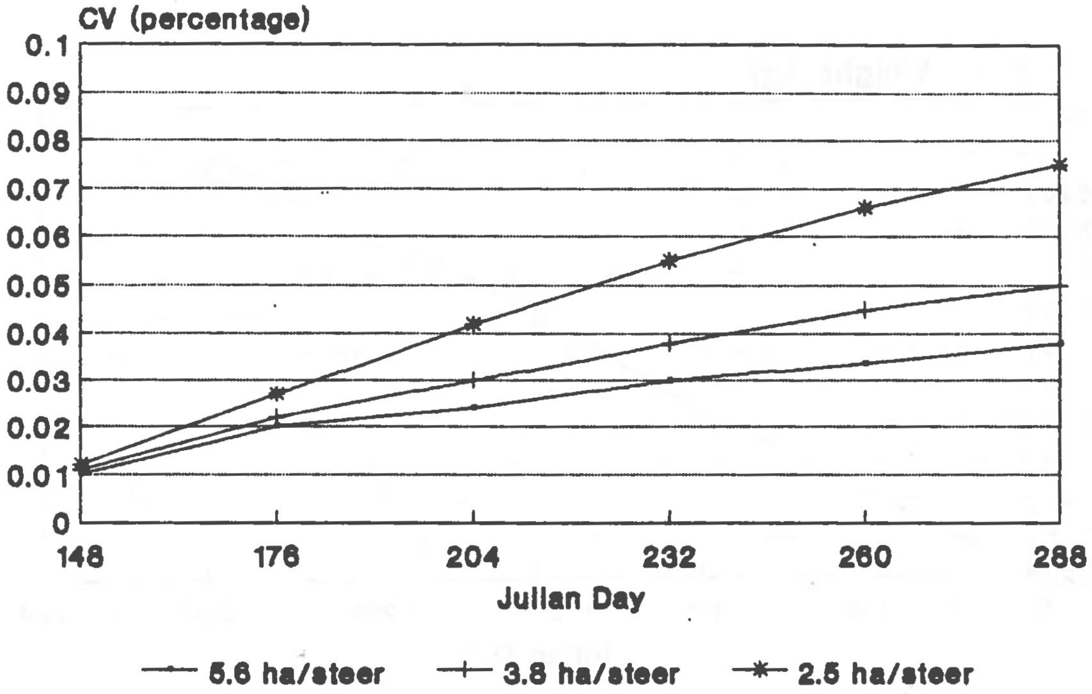


Figure 3a. Stochastically simulated, historically simulated, and experimental average daily gains for six grazing periods.

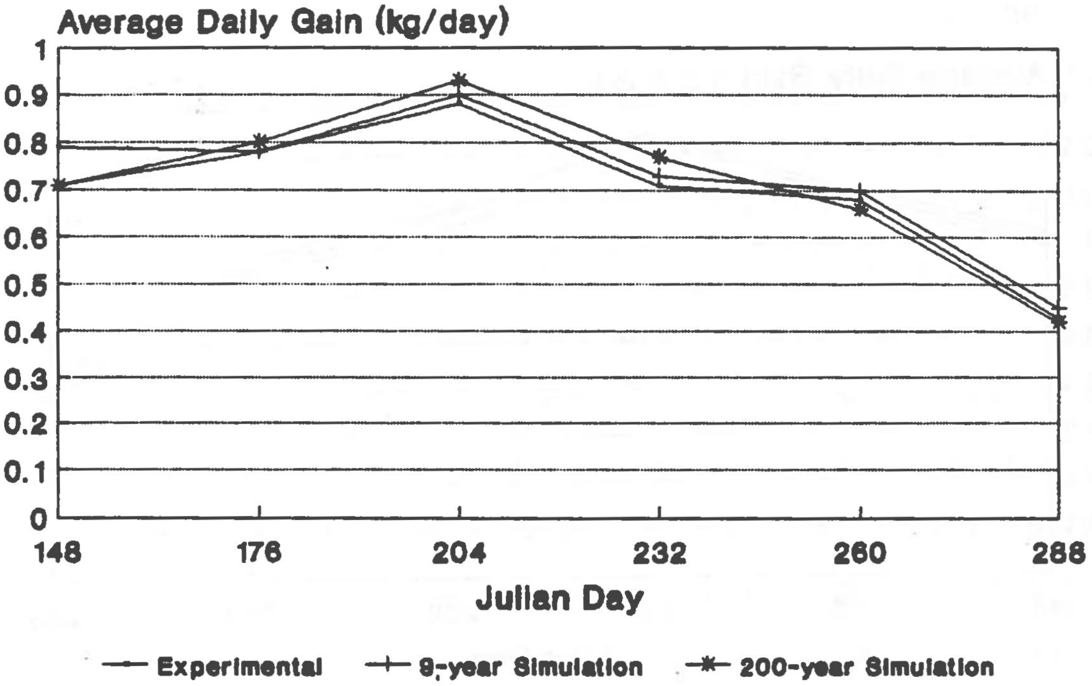
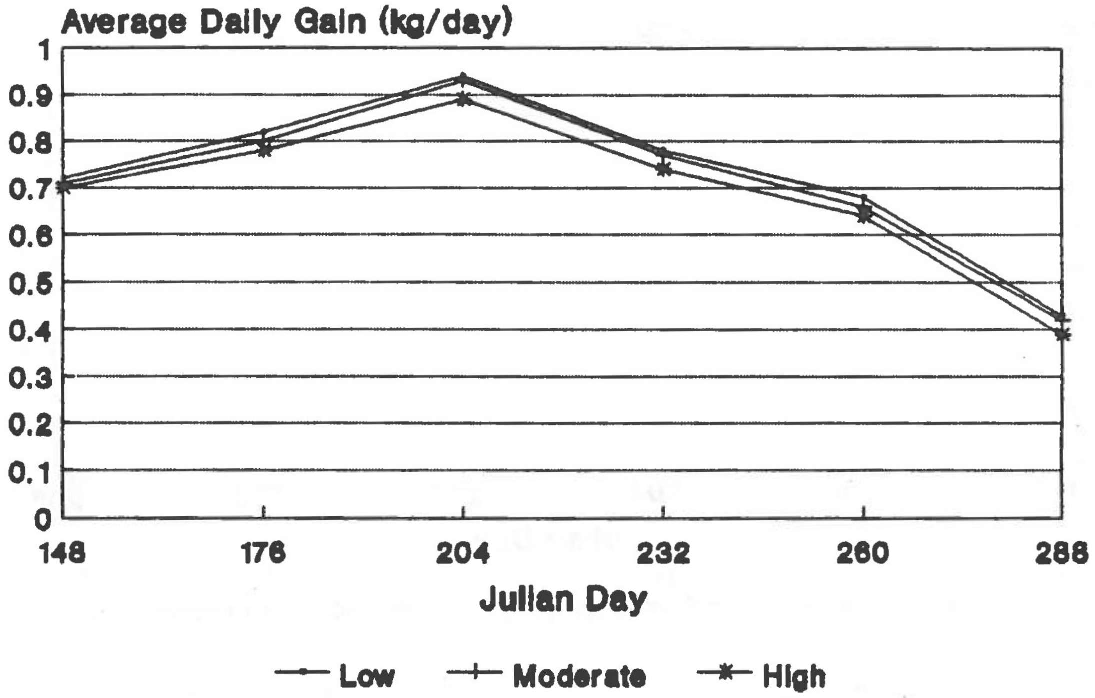


Figure 3b. Stochastically simulated two-hundred year average daily gain for six grazing periods and three stocking rates (2.5, 3.8, and 5.6 ha/steer for high, moderate, and low, respectively).



The probability distributions of the seasonal steer live-weight (Table 7) were positively skewed for all stocking rates. Figure 4 shows that, while the lightest stocking rate reached the highest probability of achieving 365 kg at the end of the grazing season, the highest stocking rate showed the largest variability in final steer weight . The probability distribution of the highest stocking rate varied from 365 kg to 225 kg. These results show that heavy stocking rates not only decrease seasonal animal performance, but also increase the probability of poor live-weight gains in years with below-normal rainfall. These results were static in the sense that no management alternatives were considered within the grazing season. The variability observed in the high stocking rate would also increase if the carry-over effect from a previous grazing season were incorporated in the simulation process. Such carry-over effect was not taken into account in this study. It is also desirable to incorporate a threshold quantity of green biomass, below which the animals are taken out of the simulation process. This modification would allow the simulation process to follow more closely real life situations. No safeguard for the deterioration of the range is taken into account by the simulation model RANGES.

Intra-seasonal probability distributions (Figure 5) show how the variability in individual steer weight and seasonal animal production under the moderate stocking rate increases as the grazing season progresses. This fact could lead producers to consider early-sales or supplementation alternatives in order to avoid financial losses in years with below-normal rainfall.

**Table 7. Probability distributions of final steer weights under three stocking rates and the corresponding seasonal animal production.**

| | PROBABILITY DISTRIBUTIONS (Percentage) | | | SEASONAL ANIMAL PRODUCTION (kg/ha)[1] | | |
|---|---|---|---|---|---|---|
| | S T O C K I N G R A T E | | | | | |
| STEER WEIGHT (KG)[1] | LOW[2] | MODERATE[3] | HIGH[4] | LOW[2] | MODERATE[3] | HIGH[4] |
| 365 | 21.5 | 15.0 | 7.5 | 24.7 | 36.4 | 55.3 |
| 355 | 62.0 | 65.0 | 67.5 | 22.9 | 33.7 | 51.3 |
| 345 | 7.5 | 10.5 | 11.5 | 21.1 | 31.1 | 47.3 |
| 335 | 4.5 | 4.0 | 3.5 | 19.3 | 28.5 | 43.3 |
| 325 | 2.0 | 2.0 | 2.0 | 17.5 | 25.8 | 39.3 |
| 315 | 0.0 | 1.0 | 1.5 | 15.8 | 23.9 | 35.4 |
| 305 | 0.5 | 0.0 | 0.0 | 13.9 | 20.6 | 31.3 |
| 295 | 1.0 | 0.0 | 2.0 | 12.2 | 17.9 | 27.3 |
| 285 | 0.5 | 0.5 | 0.0 | 10.4 | 15.3 | 23.3 |
| 275 | 0.0 | 0.0 | 1.5 | 8.6 | 12.7 | 19.3 |
| 265 | 0.0 | 0.0 | 1.5 | 6.8 | 10.1 | 15.3 |
| 255 | 0.5 | 1.5 | 0.0 | 5.0 | 7.4 | 11.3 |
| 245 | 0.0 | 0.0 | 0.0 | 3.3 | 4.8 | 7.3 |
| 235 | 0.0 | 0.5 | 1.5 | 1.5 | 2.2 | 3.4 |
| 225 | 0.0 | 0.0 | 1.0 | -.3 | -.4 | -.6 |

1 (Target weight-initial weight)/stocking rate.
2 LOW = 5.6 ha/steer during 168 days
3 MODERATE = 3.8 ha/steer during 168 days
4 HIGH = 2.5 ha/steer during 168 days

**Figure 4. Probability distributions of final steer weights for three stocking rates (2.5, 3.8, and 5.6 ha/steer for high, moderate and low, respectively) at SECRC.**

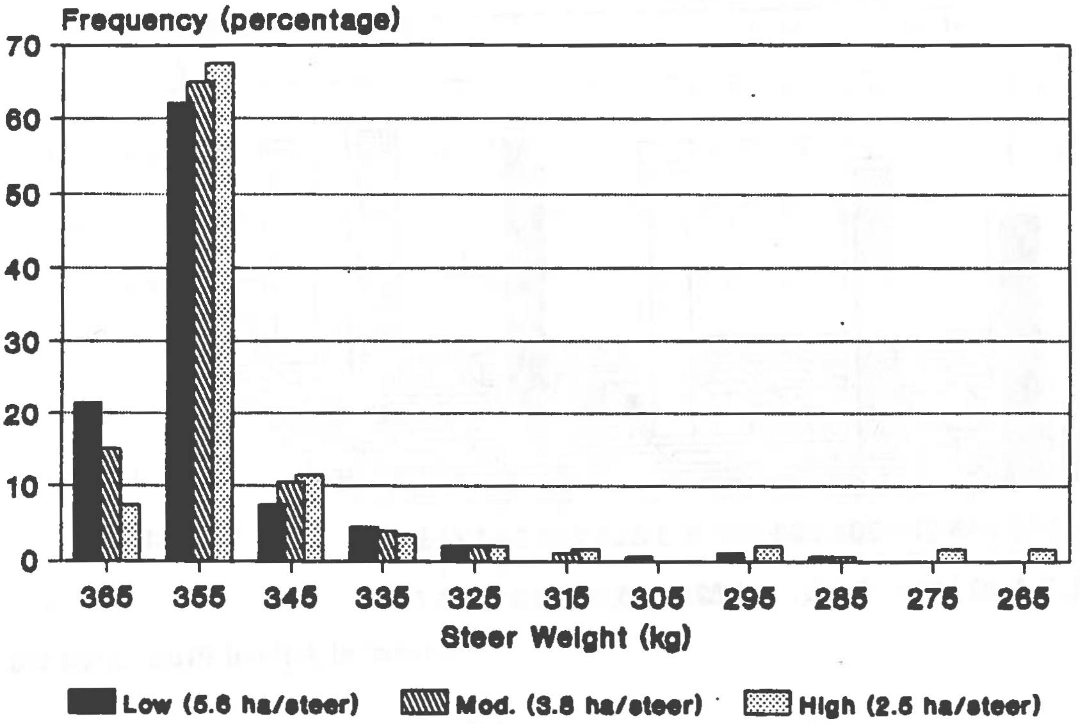
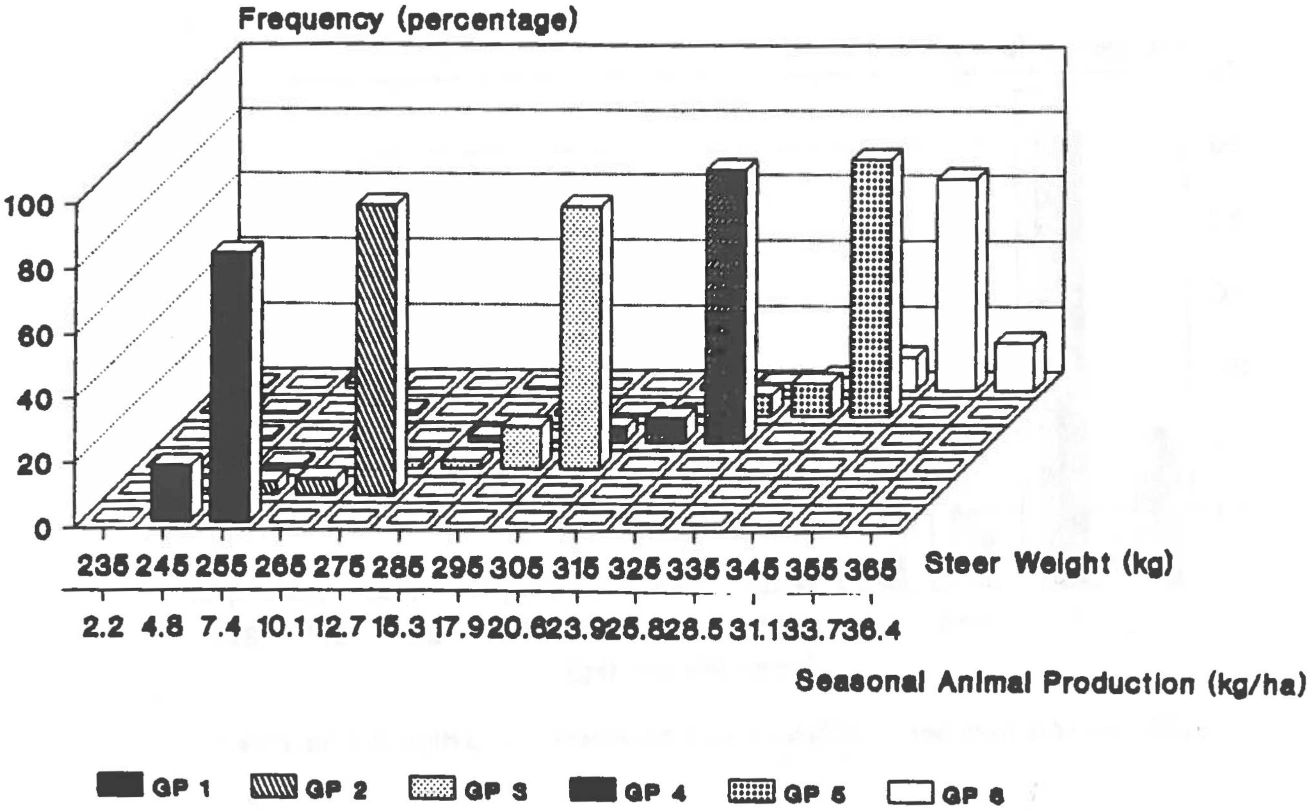


Figure 5. Intra-seasonal probability distributions of final steer weights and seasonal animal production at SECRC under moderate stocking rate (3.8 ha/steer).



GP = Grazing Period

# CONCLUSIONS

Both, the experimental and the historically simulated seasonal steer production 1969-1977 average at SECRC were 31.5 kg/ha. Both trials used a stocking rate of 3.8 ha/steer in a 168-day grazing season. Stochastic rainfall simulations of 200 years gave a seasonal animal production of 21.8, 31.6, and 46.3 kg/ha under the low, moderate, and high stocking rates. Intra-seasonal variability in steer weights and seasonal animal production increased as the grazing season progressed. The observed variability in seasonal individual steer weight gain and seasonal animal production was related to the interaction of changing forage quantity and quality.

The coefficient of variation of seasonal steer production increased from 3.8 percent at the low stocking rate, to 7.5 percent at the high stocking rate. The higher the stocking rate used to achieve a high production per area, the higher the associated risk of failing to achieve the production target.

The estimated probability distributions are indicative of the risk involved in steer production in southeastern Colorado and may have general application for the shortgrass steppe. However, caution is recommended in its use because they do not include management alternatives within a grazing season, or green biomass carry-over effects between grazing seasons. Conditional probabilities of transition between grazing periods could be estimated and used to derive conditional decision rules. These decision rules could be applied throughout the grazing season, as opposed to decision rules at the beginning or end of the grazing season.

Ecological factors of the vegetation (e.g. forage reserve levels for regrowth, available forage, etc.) or climatological trends (i.e. drought periods) could be included as part of the scenario that ranchers face in making stocking decisions. Seasonal and intra-seasonal stocking decisions are not made with ecological factors in isolation. They are made in concert with market situations. Estimations of expected forage and livestock production, selling/ buying prices, and costs of retaining cattle are necessary for risk analysis of stocker operations. Further, a utility function for ranchers in southeastern Colorado needs to be elicited. It is probable that ranchers' utility for an over-achievement of the level of production may not be the same as for an under-achievement of the same magnitude.

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