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Development and Evaluation of a Bio-economic Model for Simulating Forage-beef System Performance under Risk Conditions

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DEVELOPMENT AND EVALUATION OF A BIO-ECONOMIC MODEL FOR SIMULATING FORAGE-BEEF SYSTEM PERFORMANCE UNDER RISK CONDITIONS

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Introduction

Beef production is a leading agricultural activity in Tennessee, ranking first among all farm commodities in terms of 1985 total cash receipts (Tennessee Agricultural Statistics Service, 1988). Most of the cattle sold by Tennessee farmers are feeder calves. The foundation for this large feeder cattle industry is the abundance of pastureland throughout the state.

Uncertainties about forage and cattle production are major management concerns of Tennessee cattle producers. Seasonal and year-to-year variability in forage production can be substantial. Such variability can be attributed to seasonal shifts in climatic conditions and, to a great extent, the uncertain and fluctuating temperature and precipitation levels characteristic of the Mid-South. Temperature variation among the annual seasons is a natural occurrence that, when combined with the physiology and growth characteristics of the adapted forage species, creates annual forage production cycles. Much of this natural variation can be anticipated. Wide climatic fluctuations, however, are not as easily predicted. Continuous periods of unseasonable conditions often result in diminished pasture stands. Moreover, animal performance and grazing efficiency decline. Resulting losses in performance and efficiency of the cattle operation translate into reduced net returns. Recent years of severe drought in the Mid-South and the associated problems for cattle producers have highlighted those phenomena (Williams, 1986; McCampbell, 1988).

Short-run price uncertainty presents another problem for decision makers who produce feeder cattle. Much of the profit variability experienced by cattle producers can be attributed to market risk or fluctuations in cattle prices. Production and marketing decisions based on erroneous price expectations may lead to less-than-optimal resource use and reduced income. Likewise, uncertainty associated with purchased feed prices is also an important source of risk to cattle producers. On many farms, hay must be purchased to meet winter feed requirements during years of poor forage production. Consequently, purchased hay requirements tend to be greatest when forage prices are highest, effectively compounding the risks associated with variable forage yields.

Problem

Beef feeder calf production operations are an important part of the Tennessee cattle industry. Many producers do not realize the profit potential of new technological advances in forage and cattle production. Cow-calf producers could benefit from results of animal science and agronomic research if they are presented in a economic framework suited for use in decision making, particularly in an uncertain environment in which income and risk goals typically conflict.

Analyses prepared by agricultural economists often ignore many of the factors determining plant and animal performance because of lack of data and complexity of the relationships. Thus, a system for economic analysis that accounts for more of these factors and improves performance predictions would be highly useful as an aid in producer decision making.

Objectives

The initial objective was to develop a bio-economic forage beef simulation model suitable for comparing alternative forage grazing systems used in feeder calf production in a risk environment. This model was designed to account for climate, forage, cattle, managerial, and economic variables and to permit evaluation of both level and variability of net returns of the various systems over time. The simulation model was used to generate results to permit comparisons of four distinct production systems with respect to both technical and financial outcomes.

Overview of Methods

Because of the numerous and interrelated physical and economic relationships characteristic of the forage-beef production setting, a systems approach was adopted. Using the systems approach, alternative subsystems were identified and defined, then combined in a manner to describe the operation of the larger system. Computer simulation techniques were employed to model the subsystems and their interactions. Such techniques were sufficiently flexible to describe dynamic, stochastic, and recursive characteristics of forage-beef systems.

Five critical subsystems — climatic, forage, cattle, managerial, and economic — were specified. Initially, subsystems were examined and described as unique parameter sets and were then linked by specifying important relationships and feedbacks among parameters. Once specified, this larger

system provided an experimental laboratory in which the effects of alternative production strategies could be examined.

Experimental Design and Analytical Techniques

An experiment was designed to examine functioning of the model relative to general expectations and to evaluate outputs. A cattle operation was designated as the unit of analysis. Alternative forage-beef production systems were specified as scenarios under which performance of the model was examined. A linear programming model was used to formulate a profit-maximizing long-term plan for the cattle operation for each of the four production systems.

Each production system was simulated recursively over a 10-year planning horizon for 100 iterations. The planning horizon covered the period 1989 through 1998. After each of the 100 iterations, the cattle operation was reinitialized to the 1988 financial, environmental, and production base parameters of the system under analysis. A new set of stochastic parameters was then developed for the planning span of each iteration.

Model outputs for each production system were compared using summary statistics on both biological and economic performance variables. Means, standard deviations, minimums, and maximums were summarized for variables in each category. Output variables were evaluated according to conformity with generally recognized standards of performance.

Unit of Analysis

A farm operation designed to be characteristic of feeder calf production in southwestern Tennessee was designated as the unit of analysis. Cow-calf production in this area is predominantly supplemental to row-crop enterprises. Consequently, physical and financial resources of the cattle operation were described as those available to a supplemental enterprise on a row-crop farm.

Land Resources

Several assumptions were made about the characteristics of the farm unit used in the analysis. Such assumptions were selected to provide a working model regarded as typical for cow-calf production units in the area. A fixed inventory of land was assumed to be available for allocation between grazing and hay production during a year. The assumed farm size was large enough to justify the operator possessing the expertise and capital base necessary to invest in and manage the production practices under examination. In this respect, 200 acres of openland was judged sufficient to support a cattle operation of approximately 100 cows.

Level and variation in yield of various forage species have been found to be quite different among the different soil series of West Tennessee (Fribourg, 1988a). Soil series classifications and the assumed proportions of each soil on the 200-acre cattle operation are shown in Appendix Table 1. Distribution of acreage among the various soil types was developed using 1982 National Resource Inventory data (U.S. Department of Agriculture/Iowa State University, 1987) for southwest Tennessee.

Labor Resources

The operator and his family were assumed to supply 80 hours of labor per week: 50 hours of operator labor and 30 hours of family labor. The amount of available labor for cattle was determined by deducting from the monthly supply the amount required in row-crop enterprises. The farm was assumed to produce cotton and soybeans, the two major crops of southwestern Tennessee, in addition to cattle. In a sample of West Tennessee beef producers, approximately 40 percent of annual gross income was obtained from beef production (Kimery, 1987). Cotton and soybean acreages (110 and 250 acres, respectively) were set to provide the remaining 60 percent of annual gross income. The assumed labor supply, the estimated crop labor requirements, and the residual amount of available labor for cattle production in each month are shown in Appendix Table 2. Any additional required labor was available for hire at the time and in amounts needed at the assumed wage charge.

Machinery and Facility Resources

The list of assumed machinery and livestock facility items required of the cattle operation along with purchase price, salvage value, and expected life are shown in Appendix Table 3. Most items were necessary for feeder cattle production regardless of the system utilized, although usage rates varied by production system. Each item was valued at its estimated purchase price in 1988 and assumed to be replaced at the end of its economic (useful) life.

Cattle facility and equipment items were specified according to technical recommendations (Midwest Plan Service, 1977) for 200 acres of pasture and a projected herd size of 100 cows. Equipment necessary to establish, renovate and maintain pastures, and to prepare, bale, and handle hay production in the form of large round bales were assumed to be available to the operation.

Forage-Beef Production Systems

Four forage-beef production systems were simulated. Forage systems included pastures of tall fescue and of bermudagrass interseeded with tall fescue. Each forage system was used in combination with spring- and fall-calving beef herds.

Forage Systems

Perennial grass species of tall fescue and bermudagrass provided the base source of forage for the cattle grazing systems. Once established, each species was assumed to have a productive life of ten years before re-establishment was necessary. One-tenth of the pastureland, or 20 acres, was re-established in each year of the 10-year planning horizon. This assumption minimized the amount of acreage idled for re-establishment in any year, while spreading costs of establishment evenly over the years. Operational sequence, timing, and performance rates for pasture management and hay harvesting in each forage system are shown in Appendix Table 4.

Acreage re-established in the tall fescue system was idled in July and not grazed until the next year. Seedbed preparation and fertilization occurred in July through August, with fescue sown in late August to allow the young seedlings to become established during the fall season (Buckner, 1985). Annual maintenance included nitrogen applications at a rate of 30 pounds per acre in March and September, and summer mowing for weed control.

Bermudagrass/tall fescue systems require much more management than tall fescue systems. Hybrid bermudagrass must be established from sprigs (Burton and Hanna, 1985), increasing both machinery and labor time. Acreage re-established in this system was idled in March and April for seedbed preparation and fertilization. In April, bermudagrass sprigs were purchased and scattered using a manure spreader and were then lightly disked to incorporate sprigs and herbicide into the soil. Once established, bermudagrass was not grazed during the summer, but was available for hay production. The bermudagrass stand was lightly disked in the fall before drilling fescue seed in 10-inch rows. Pastures were idled until the following year to allow establishment of the fescue seedlings. Nitrogen was applied in March and September at an annual rate of 45 pounds per acre.

During the grazing season, acreage was set aside for needed hay production to overwinter the beef herd. Two cuttings of hay were possible. First cutting hay was harvested in June and consisted of accumulated forage growth during April, May, and June. Second cutting hay included accumulated growth in July, August, and September. Hay was prepared and handled in the form of large round bales (1,200 pounds), and stored on the ground with plastic covering. During normal years, hay was fed in December through February.

Calving Systems

Beef herds in each calving system were divided into five animal classifications: cows, calves, weaned heifers, replacement heifers, and bulls. Forage requirements of each class varied during the year according to the production cycle of each calving system, and the age and weight of animals (National Research Council). Requirements for lactation, gestation, and maintenance of a 1,000-pound cow were obtained from the forage. Calves utilized forage, as well as dam's milk, for growth. Twenty percent of cow numbers were retained as replacement heifers at weaning. Once bred, 17 percent of cow numbers comprised the replacement heifer category. Growth requirements for each heifer class were met by feeding forage. The cow-to-bull ratio was 25 to 1. Bulls required forage to maintain an average weight of 1,200-pounds (Johnson, 1987b).

Cow herds in each system were culled annually at weaning (spring herd — October; fall herd — June). The annual 17-percent culling rate included nonpregnant cows, dry cows, and cows that had reached the end of their economic life. Heifer calves saved at weaning were bred at 15 months of age. After breeding, heifers were pregnancy-checked and 15 percent (or 3 percent of cow numbers) were sold as nonbreeders. Replacement heifers calved as 2-year-olds. Bulls were assumed to be purchased at 2 years of age and sold after reaching 8 years of age.

Labor requirements by month for fall- and spring-calving herds are shown in Appendix Table 5. Requirements indicate the number of hours needed in each month for herd observation and performance of managerial tasks. Labor needs varied throughout the year with each herd's production cycle and seasonal management priorities.

Forage and Cattle Financial Requirements

Expenses incurred with the forage and calving systems were developed using procedures described in the Oklahoma State budget generator (Kletke, 1979). Production data and prices were specified to reflect 1988 production practices and costs. Prices and costs were dynamic variables in the simulation analysis and changed from year to year according to assumed economic conditions.

Per-acre expense for each forage system and hay harvesting are shown in Appendix Table 6. Per-cow expenses for beef cow-calf production are presented in Appendix Table 7. Cow-calf expenses are identical for both spring- and fall-calving systems because little difference existed between the two for

the identified items. Requirements and associated costs for pasture and hay were omitted because of their variation with forage and calving system. Production data and costs used in the expense budgets were obtained from Johnson (1987b), Halbrook et al. (1986), and the Tennessee Agricultural Statistics Service (1988).

Model Design

A bio-economic Monte Carlo simulation model that is dynamic, stochastic, and recursive was developed for use in this study. The simulation model was used to determine biological and financial performance for each of the four distinct forage-cattle production systems over a 10-year planning horizon. The model structure included six components: climatic, forage, cattle, managerial, price and cost, and budgetary operational parameters. Interactions and feedbacks among these parameters gave the simulator its operating structure. Forage and cattle variables were evaluated on a monthly basis and were used to determine relevant management decisions. Organization of the model and relationships and feedbacks among parameter sets are illustrated in Figure 1.

Climatic Parameters

Monthly temperature and precipitation were deemed crucial in developing forage production relationships. A measure of temperature in terms of ranges tolerated by each species was needed to assess forage productivity. A heat-unit model described by Owens and Moore (1974) was adopted for this purpose. Their model for determining rate of maturity can be generalized with the following formulation:

$$(1)\quad EHU = [\,(T + t / 2) - (T - MAXT)\,] - MINT$$

where:

EHU = effective heat units, °days
T = maximum daily temperature, °F
t = minimum daily temperature, °F
MAXT = "maximum" base temperature above which temperatures do not contribute to plant growth, °F
MINT = "minimum" base temperature below which plant growth is minimal, °F

Specification of the "maximum" and "minimum" base temperatures for tall fescue was 90°F and 50°F, respectively, and 100°F and 65°F, respectively, for bermudagrass (Fribourg, 1988b; Buckner, 1985; Burton and Hanna, 1985).

Monthly precipitation and temperature data were obtained from the National Oceanic and Atmospheric Administration, Brownsville Weather Station for the years 1951 through 1987. The past 37 years were assumed to provide a valid representation of precipitation and temperature distributions that could occur over the planning horizon. To generate stochastic sequences of monthly climatic data, multivariate empirical probability density functions (pdf's) were developed for monthly precipitation and maximum and minimum temperatures (VanTassell, Richardson, and Conner). Means, standard deviations, and ranges are given in Table 1 for the historical and the generated climatic variables simulated over the 10-year span for 100 iterations.

Forage Parameters

The simulated climatic variables were used to determine forage yield and quality each month. Climatic effects on forage productivity are cumulative. The forage production relationship was specified by relating monthly forage yield to accumulated climatic variables, using January 1st as the beginning of each forage production year.

Forage Yield Estimation. The relationship between accumulated forage yield (lbs. dry matter per acre) and accumulated climatic variables was estimated using experimental data obtained from the Ames Plantation Experiment Station in southwest Tennessee. Forage data were collected from experimental plots of tall fescue, bermudagrass/tall fescue, and bermudagrass maintained through 1980-1983. Experimental design incorporated plots on six soils (Lexington, Grenada, Memphis, Loring, Calloway, and Henry series), with three replications for each forage (Fribourg, 1988a). Growth on each plot was cut, bagged and weighed at various times during each year. Forage yield was therefore measured as the cumulative annual yield to each cutting date. Climatic variables, also measured at the Ames Plantation, were used to relate forage yield response to environmental conditions. Cumulative climatic variables were measured as the amounts of annual precipitation and effective heat units accumulated to each cutting date. Ordinary least-squares were used to estimate the growth-climate relationship of each forage evaluated in this study.

A log-reciprocal form was specified for the tall fescue and bermudagrass/tall fescue equations. This form is restricted to emanate from the origin. The shape exhibited by this function generally follows that of accumulated forage growth. Annual growth begins slowly in late winter months, becomes rapid during the spring and early summer, and tapers as the year progresses. In contrast, a reciprocal form was specified for the bermudagrass equation. Forage growth of bermudagrass does not

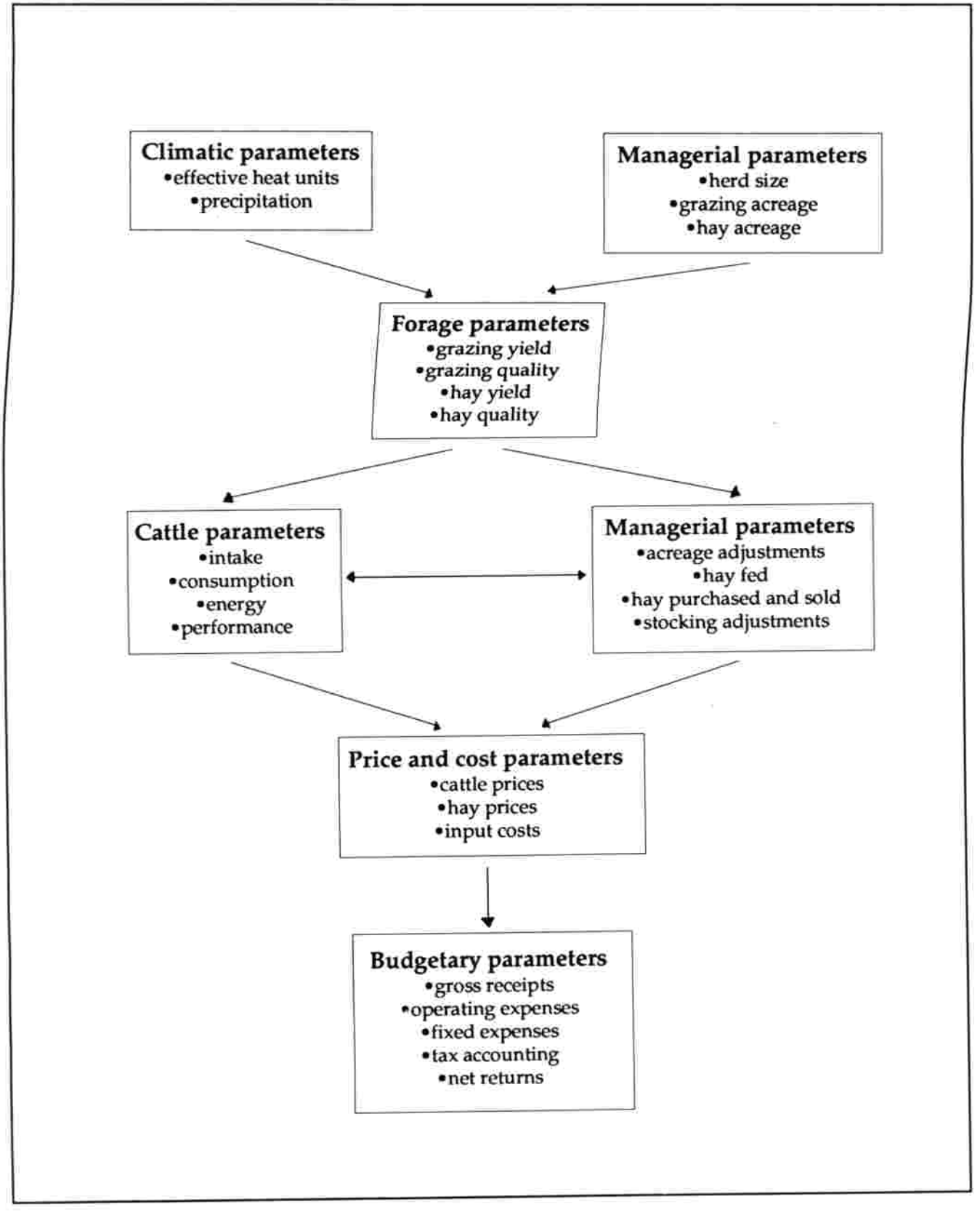


Figure 1. Schematic of the bio-economic simulation model.

Table 1. Selected statistics for the actual and simulated monthly precipitation and temperature levels. *

Month	Mean		Standard Deviation		Minimum	Maximum
	Actual	Simulated	Actual	Simulated		
Precipitation			Inches			
January	4.25	4.27	2.79	2.83	0.61	11.49
February	4.39	4.46	2.30	2.37	1.20	10.67
March	5.22	5.27	2.53	2.61	0.64	12.18
April	5.56	5.64	2.40	2.43	1.25	10.55
May	5.35	5.54	3.28	3.52	0.67	18.01
June	3.52	3.68	1.82	1.89	0.53	8.09
July	4.08	4.05	2.23	2.21	0.25	9.22
August	3.02	3.00	2.39	2.46	0.05	10.42
September	3.57	3.65	2.03	2.04	0.00	7.67
October	2.67	2.73	1.71	1.72	0.00	7.54
November	4.49	4.60	2.46	2.56	1.14	11.06
December	4.94	4.97	3.07	3.15	0.53	13.23
Maximum Temperature			°F			
January	47.49	47.26	5.50	5.66	33.48	55.65
February	52.86	52.74	5.47	5.71	37.57	61.48
March	62.00	61.95	4.97	5.17	49.35	71.26
April	73.14	76.12	3.66	3.59	63.40	78.33
May	81.09	81.05	3.32	3.44	74.13	90.06
June	88.47	88.30	2.53	2.61	83.40	95.15
July	91.50	91.51	2.40	2.55	86.42	97.97
August	90.69	90.76	2.98	3.13	85.58	98.67
September	84.93	84.97	3.58	3.81	76.93	93.00
October	74.79	74.86	3.67	3.69	68.06	85.81
November	62.00	61.84	3.36	3.37	52.87	67.60
December	51.83	51.69	4.33	4.58	39.26	59.90
Minimum Temperature			°F			
January	28.25	28.00	5.34	5.39	16.10	38.42
February	32.18	32.12	4.69	4.92	20.32	39.96
March	40.37	40.42	3.95	4.07	29.35	48.06
April	50.18	50.19	2.97	2.92	43.73	55.80
May	58.50	58.40	2.91	3.02	52.48	63.90
June	66.14	66.05	2.40	2.41	61.13	72.93
July	69.74	69.75	1.80	1.92	66.29	73.71
August	67.82	67.69	2.02	2.13	63.45	71.37
September	60.88	61.04	2.83	2.85	56.00	66.37
October	48.71	48.58	3.74	3.92	41.77	57.65
November	39.73	39.78	3.31	3.32	30.67	47.03
December	32.47	32.31	4.54	4.61	23.03	41.32

* Maximums and minimums are identical for the actual and simulated data.

initiate until the warmer conditions of April and May. With this form, the onset of annual production was indicated by accumulated climatic conditions. Both log-reciprocal and reciprocal forms approach a maximum. One would expect that a biological maximum exists for each forage species, albeit unknown.

The forage yield equations used in this study, along with their accompanying statistics are shown in Table 2. Each equation relates accumulated forage yield (lbs. dry matter per acre) to accumulated climatic variables at common days during each year. In all equations, the effective heat unit variable was significant at the 95-percent level with expected sign. Precipitation variables were specified as interaction terms with the discrete soil variables. Accumulated precipitation was highly correlated with the heat unit variable. By using the climate-soil interaction, the impacts of the inherent collinearity were reduced while including the explanatory power of yield variation due to the moisture-retaining capability of each soil. The Calloway soil was deleted in each equation for estimation purposes. Parameter estimates therefore measure yield difference between the Calloway-precipitation interaction and the other soil-precipitation interactions.

Year effects were included as discrete variables (YR2 & RYRS) in each equation. The establishment year was deleted in order to examine patterns of forage growth in post-establishment years. Parameter estimates therefore indicate yield differences associated with time from establishment. In all equations, year variables were significant at the 95-percent level. Average production was lowest in the establishment year and highest in year two. After year two, average production diminished. Unfortunately, more years of data were unavailable so that persistence of the forages could not be fully specified over their useful lives.

Each acre of land on the cattle operation was assumed to include a fixed percentage of soils. Further, the land resource was divided into ten tracts of 20 acres each. Monthly yields were projected for each forage-soil-year combination. Per acre yields were calculated using the assigned percentage of soils on each representative acre. Next, tracts were assigned a specific year according to assumed date of establishment. Per-acre yield estimates were specified for each tract according to its assumed year of productive life.

Limited data and restrictions imposed by the functional form specified in each equation resulted in monthly yield estimates in some months that were contradictory to general contention. Production data were unavailable for much of the winter season and oftentimes were not collected at regular intervals during the grazing season. Restrictive properties of each functional form also precluded estimates exhibiting typical forage production peaks and slumps, such as the summer slump exhibited by tall fescue. Consequently, procedures were necessary to address these shortcomings. Yield estimates were aggregated into 3-month intervals, or seasons, beginning January 1st.

Monthly yields within each season were specified using secondary data on the annual production distribution of forages in Tennessee (Fribourg, 1983). Seasonal estimates were desegregated into monthly yields according to the percentage of seasonal yield that normally occurs in each month. Thus, monthly yields within a season exhibit production patterns which typify the season. Seasonal yield differences, however, are the consequence of climatic variability. Monthly grazing and hay yields for each forage, simulated under normal climatic conditions, are shown in Table 3. Per acre yields are presented for both grazing and hay production. Grazing yields included a 10-percent loss.in forage due to cattle damage of the pasture stand while grazing. Two cuttings of hay were possible in each year. Hay yields included forage accumulated during each season designated for hay production and were specified for the months in which hay would be harvested. A 10-percent yield loss was assumed for hay harvesting (Fribourg, 1988b).

Forage Quality Estimation. Because the forage data did not include measurements of quality, secondary data were employed to specify the quality (percent total digestible nutrients) of the forages in each month. Stage of maturity and length between grazings (or cuttings) were deemed most critical in developing forage quality parameters. Thus, quality was estimated in each month for grazing and in each of the two hay-production seasons. Monthly quality was generated using grazing and hay estimates for forages in different stages of maturity (National Academy of Sciences), along with expert consultation (Fribourg, 1988b).

Total forage quality was the weighted average quality of each species. A range of occurrence for bermudagrass growing with tall fescue was used to specify bounds within which the percentage of each species was assumed to vary in each month (Fribourg, 1988b). Monthly grazing and hay forage quality, simulated under normal climatic conditions for each forage, are presented along with the monthly yields in Table 3.

Hay Inventory. Hay production in each system was added to an inventory maintained on the operation. Beginning and ending hay inventories were determined each month after additions or deductions

Table 2. Forage yield ordinary least-squares equations[a] for each forage.

Tall Fescue[bc]

$$TFY = \underset{(117.7)^{**}}{9.30} - \underset{(-30.8)^{**}}{8041.54\ TFHU} - \underset{(-8.2)^{**}}{10392.37\ PXLEX} - \underset{(-0.4)}{507.29\ PXGREN}$$

$$- \underset{(-4.9)^{**}}{5234.29\ PXMEM} - \underset{(-3.1)^{**}}{3778.53\ PXLOR} + \underset{(7.9)^{**}}{12103.29\ PXHEN} + \underset{(7.2)^{**}}{0.50\ YR2}$$

$$+ \underset{(2.1)^{**}}{0.15\ RYRS} + \varepsilon$$

$R^2 = 0.84$ STD DEV = 0.54 N = 525

Bermudagrass/Tall Fescue

$$BFY = \underset{(66.6)^{**}}{8.55} - \underset{(-21.3)^{**}}{11479.73\ BFHU} - \underset{(-2.4)^{**}}{4840.32\ PXLEX} - \underset{(-0.5)}{1063.42\ PXGREN}$$

$$- \underset{(-1.2)}{2122.26\ PXMEM} - \underset{(-1.2)}{2501.12\ PXLOR} + \underset{(4.8)^{**}}{10334.95\ PXHEN} + \underset{(9.5)^{**}}{1.58\ YR2}$$

$$+ \underset{(8.2)^{**}}{1.05\ RYRS} + \varepsilon$$

$R^2 = 0.77$ STD DEV = 0.69 N = 393

Bermudagrass

$$BGY = \underset{(15.6)^{**}}{8860.78} - \underset{(-13.7)^{**}}{36948317.36\ BGHU} + \underset{(0.96)}{10227552.97\ PXLEX} + \underset{(2.8)^{**}}{30798082.40\ PXGREN}$$

$$+ \underset{(1.4)}{14914250.79\ PXMEM} + \underset{(1.3)}{16101885.06\ PXLOR} + \underset{(5.5)^{**}}{88282003.22\ PXHEN}$$

$$+ \underset{(8.8)^{**}}{3941.96\ YR2} + \underset{(8.8)^{**}}{2806.90\ RYRS} + \varepsilon$$

$R^2 = 0.62$ STD DEV = 1606.49 N = 232

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[a] A log-reciprocal form was fitted for the tall fescue and bermudagrass/tall fescue equations, while a reciprocal form was fitted for the bermudagrass equation.

[b] t-values for each parameter are in parentheses below parameter estimates.

[c] Accumulated precipitation was specified as an interaction term with binary soil variables. Thus, the values of interaction terms are determined by accumulated precipitation times, 1 if soil type, 0 otherwise.

* Significant at the 90-percent level.

** Significant at the 95-percent level.

where:

STD DEV	= standard deviation
N	= number of observations
TFY	= log of accumulated tall fescue yield (lbs DM per acre)
BFY	= log of accumulated bermudagrass/tall fescue yield (lbs DM per acre)
BGY	= log of accumulated bermudagrass yield (lbs DM per acre)
TFHU	= reciprocal of accumulated tall fescue heat units (°days)
BFHU	= reciprocal of accumulated bermudagrass/tall fescue heat units (°days)
BGHU	= reciprocal of accumulated bermudagrass heat units (°days)
PXLEX	= reciprocal interaction between accumulated precipitation (hundreds of inches) and the Lexington soil series
PXGREN	= reciprocal interaction between accumulated precipitation (hundreds of inches) and the Grenada soil series
PXMEM	= reciprocal interaction between accumulated precipitation (hundreds of inches) and the Memphis soil series
PXLOR	= reciprocal interaction between accumulated precipitation (hundreds of inches) and the Loring soil series
PXHEN	= reciprocal interaction between accumulated precipitation (hundreds of inches) and the Henry soil series
YR2	= year following establishment (1981)
RYRS	= years following second year (1982 & 1983)
ε	= residual error term

were made. The first and second cuttings of hay were added to inventories at the ends of June and September, respectively. Inventory at the beginning of each month was available for feeding or sale during the month. Decision parameters, described in the next section, specified how the hay inventory was managed.

Managerial Parameters

Managerial parameters were used to describe the decision process used by cattle producers to control the forage-beef system. Two sets of decisions characterized the decision-making process. Long-term decisions described the plan formulated by cattlemen to manage the operation for the 10-year span. Such decisions included long-term stocking level and annual grazing and hay management. These plans were formulated for each system under normal environmental conditions. In the short-term, fluctuations in climatic conditions necessitate a revision of plans. Short-run decisions include necessary adjustments in grazing and hay management, hay feeding, hay purchase and sale, and ultimately stocking level if necessary.

Long-Term Decisions. A linear programming model was used to formulate a long-term plan for the cattle operation with each production system. The LP model was specified with a profit maximizing objective constrained by the resource availability, the necessity to balance forage production and animal requirements, and animal intake capacity. In matrix notation, the model is expressed as follows: Find vectors X1...X6, which maximize:

$$(2)\quad \pi = \begin{bmatrix} C1 & C2 & C3 & C4 & C5 & C6 \end{bmatrix} \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \\ X6 \end{bmatrix}$$

subject to

$$(3)\quad \begin{bmatrix} A11 & & & & & \\ A21 & A22 & A23 & & & \\ & & A33 & & A35 & \\ & A42 & & A44 & A45 & \\ & A52 & & A54 & A55 & \\ & & A63 & & & \\ A71 & & & A74 & A75 & A76 \end{bmatrix} \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \\ X5 \\ X6 \end{bmatrix} \begin{matrix} \\ \\ < \\ = \\ \\ \\ \\ \end{matrix} \begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \\ B6 \\ B7 \end{bmatrix}$$

$$Xi \geq 0 \; (i = 1,...,6)$$

where

π = annual profit

C1 = vector of annual pasture production costs
C2 = 0
C3 = vector of hay production costs

Table 3. Monthly forage yield* and quality simulated under normal climatic conditions for grazing and hay production.**

Month	Tall fescue yield	quality	Bermudagrass/tall fescue yield	quality	Bermudagrass yield	quality
Grazing yield						
January	23.74	35.00	23.54	35.00	—	—
February	85.45	40.00	84.74	40.00	—	—
March	365.53	68.00	362.51	68.00	—	—
April	689.48	65.00	518.89	64.80	816.46	63.00
May	614.94	62.00	730.28	62.35	1020.57	63.00
June	559.04	57.00	672.63	57.00	1564.88	57.00
July	476.84	52.00	646.08	52.00	979.92	52.00
August	460.40	52.00	593.69	50.72	769.94	50.00
September	707.05	60.00	506.39	55.00	633.29	50.00
October	717.05	60.00	875.16	55.39	532.68	50.00
November	432.70	55.00	391.86	52.00	238.00	45.00
December	86.54	48.00	169.81	48.00	—	—
Total	5218.76		5575.56		6555.74	
Hay yield***						
June	1863.47	60.00	1921.80	59.35	3401.91	58.00
September	1647.54	55.00	1746.15	52.05	2383.15	50.00
Total	3511.01		3667.95		5785.06	

* Forage yield is measured in pounds of dry matter per acre. Yield estimates are averages for each month across all tracts of land and include a 10-percent loss in forage due to grazing.

** Forage quality is measured in percent total digestible nutrients.

*** Hay yield is specified for the 2 months in which hay is harvested (1st cutting — June; 2nd cutting — September). Hay yields were reduced 10 percent for losses at harvesting (Fribourg, 1988b).

C4 = vector of net returns from cattle production
C5 = 0
C6 = vector of purchased labor costs

X1 = vector of pasture production activities (acres)
X2 = vector of pasture consumption activities (head)
X3 = vector of hay production activities (acres)
X4 = vector of cattle production activities (head)
X5 = vector of hay consumption activities (head)
X6 = vector of purchased labor activities (hours)

A11 = matrix of land restrictions for each tract of land
A21 = matrix of mean monthly forage yields
A22 = matrix of maximum monthly grazing intake parameters
A23 = matrix to transfer monthly pasture production to hay production
A33 = vector to accumulate and transfer hay production to A_{35}
A35 = vector of maximum monthly hay intake parameters
A42 = matrix of energy available from maximum monthly grazing intake
A44 = matrix of monthly cattle energy requirements
A45 = matrix of energy available from maximum monthly hay intake

A52 = unit matrices to impose constraints so that grazing and hay consumption do not exceed maximum intake capacity
A54 = unit matrices to impose constraints so that grazing and hay consumption do not exceed maximum intake capacity
A56 = unit matrices to impose constraints so that grazing and hay consumption do not exceed maximum intake capacity
A63 = unit matrix to impose constraints so that acreage set aside for hay production in each haying season is identical in the three months of each haying season
A71 = matrix of monthly labor requirements for pasture activities
A74 = matrix of monthly labor requirements for cattle activities
A75 = matrix of monthly labor requirements for hay activities
A76 = matrix to accumulate purchased labor required each month

B1 = vector of available land resources on each tract to which the ≤ restraint applies
B2 = null vectors to which the ≤ restraint applies
B3 = null scaler to which the = restraint applies
B4 = null vectors to which the ≤ restraint applies
B5 = null vector to which the ≤ restraints apply
B6 = null vector to which the ≤ restraints apply
B7 = vector of available labor resources each month to which the ≤ restraint applies

Model design was such that results could easily be used in the simulation analysis. Structure of the LP model is apparent from equations 2 and 3. Specific model features and their details, however, warrant clarification.

Return and expense information was needed to specify the LP objective function. Estimated annual returns per cow for spring- and fall-calving herds are displayed in Table 4. Cattle prices were specified in the appropriate months of selling for each herd (spring herd — October; fall herd — June) using 5-year average prices during the 1983-87 period, indexed to 1988 levels (Federal Reserve System, 1989). Price data were obtained from Tennessee feeder calf auctions (Tennessee Agricultural Statistics Service). Animal weights were set according to an average calf weaning weight of 500 pounds, a non-breeding heifer weight of 640 pounds, and culled cow and bull weights of 1,000 and 1,200 pounds, respectively.

Features common to the simulation and LP models included the specification of monthly periods for available and required forage and labor, division of the land resource into ten tracts, division of the beef herd into five animal classes, and use of the net energy system (National Research Council, 1984) for expressing nutrient values and requirements. The land resource (200 acres) was divided into ten tracts of 20 acres. Yields simulated under normal climatic conditions were used to specify forage production on each tract. Forage was available to be grazed or transferred to hay production with a 10-percent yield loss for grazing and hay harvesting, and an additional 15-percent loss for hay storage and feeding (Fribourg, 1988b). Acreage idled for hay production in any month of a haying season was constrained to be idled in other months of the season. Cattle intake and energy constraints were included as availabilities and requirements per month for cows, calves, weaned heifers, replacement heifers, and bulls. The net energy system was used to express energy values of cattle intake and requirements for maintenance (cows & bulls) and growth (calves & heifers).

Intake restrictions were specified in the LP formulation to account for the possibility that an animal may consume its intake capacity and still not satisfy energy requirements. The relationship between forage quality and intake estimated by Conrad et al. (1966) was used to develop maximum animal consumption capacities for grazing and hay in each month. Constraints were imposed so that grazing and hay consumption did not exceed maxi-

Table 4. Estimated beef cow-calf returns per cow used in the long-term planning (LP) model for Spring- and Fall-calving herds.

Item	Weight each	Unit	Unit price* Spring herd	Unit price* Fall herd	Quantity	Total value Spring herd	Total value Fall herd
Gross receipts**							
Steer calves	5.5	CWT	69.99	70.73	0.44	169.38	171.17
Heifer calves	4.6	CWT	61.76	63.59	0.24	68.18	70.20
Nonbred heifers	6.4	CWT	57.34	58.37	0.03	11.01	11.21
Culled cows	10.0	CWT	40.01	44.20	0.16***	64.02	70.72
Aged bulls	12.0	CWT	50.01	55.25	0.01	6.00	6.63
					Total gross returns	318.59	329.93
					Total expenses****	149.05	149.05
					Total net returns*****	169.54	180.88

*Cattle prices are average Tennessee prices in October (Spring herd) and June (Fall herd) from 1983 through 1987, normalized to 1988 dollars.

**Assumes an 88-percent calf crop and 17-percent replacement rate.

***Assumes a 1-percent death loss for cows.

****Total expenses are for cattle production exclusive of forage production costs and charges for land, labor, and capital.

*****Total net returns are returns to land, labor, capital, and forage resources.

mum intake capacities (Whitson et al., 1976). The net energy system was used to describe available energy for maintenance and growth from maximum animal intake capacity. Monthly available energy from each forage system was matched with monthly requirements of each calving system to determine stocking level, grazing, and hay management of the operation for each production system.

Results of the long-term planning model are reported in Table 5. Herd sizes and hay acreages shown are the long-term decision parameters used in the simulation model for each production system.

Short-term Decisions. The amount and quality of available forage during a year was determined by climatic conditions. Short-term decisions were exercised in response to the resultant monthly forage production. If normal (or average) forage conditions prevailed, winter hay feeding level was the only short-term decision rendered. Variations from the long-term plan were unnecessary. In the event of surplus forage, long-term profit maximizing stocking and hay production levels were maintained. Surplus hay was sold after the second cutting in October. Hay production in excess of that required during a normal winter, minus a 10-percent reserve for severe or extended winters, was sold. Managerial response to months of deficit forage was more complex. Several options including grazing hay acreage, feeding extra hay, buying hay, and reducing stocking level were available. Assumed use of each option varied by timing of the short forage supply and status of the forage and cattle systems.

Short-term decisions made in response to deficit forage production were specified in each of two annual periods, the grazing season (March through November) and the winter season (December through February). The sequence by which

Table 5. Results of the long-term planning model — decision parameters used in the simulation analysis for each production system.

Item	Unit	Spring herd		Fall herd	
		Tall fescue	Bermudagrass/ tall fescue	Tall fescue	Bermudagrass/ tall fescue
Herd size					
Cows	head	101	126	104	126
Calves	head	89	111	92	111
Weaned heifers	head	20	25	21	25
Replacement heifers	head	17	21	18	21
Bulls	head	5	6	5	6
Hay production*					
Cutting 1	acre	70	50	50	40
Cutting 2	acre	0	20	30	40

*Acreage of hay production at each cutting is the sum across all tracts of land. Hay production on each tract was specified in the simulation model. Acreage on each tract was rounded to the nearest ten acres to facilitate management and division of tracts for hay.

actions were exercised to offset forage deficits during the grazing season was:

1. graze hay acreage
   - up to 50 percent of first cutting hay acreage
   - up to 100 percent of second cutting hay acreage

2. feed hay from inventory
   - up to 100 percent of inventory prior to first cutting
   - up to 50 percent of inventory after first cutting

3. wean and sell calves early
   - only in the two months prior to scheduled weaning

4. sell cows

Grazing acreage set aside for hay production was the first option exercised during these periods. Animals were allowed to graze hay land in increments of 10 acres until enough acres were used to meet the forage deficit. Only 50 percent of first cutting hay acreage was available for diversion, while 100 percent of second cutting hay could be grazed. Forage yield on these diverted acres was equivalent to hay growth accumulated during months prior to grazing with the assumed 10-percent grazing loss, plus an additional 5-percent loss due to increased trampling of the accumulated growth. Feeding hay from inventory was the next option. Prior to harvesting first cutting hay (January through June), all hay in inventory was available for feeding (i.e. hay remaining from the previous year). After first cutting hay was harvested, a maximum of 50 percent of hay inventory was allowed for summer feeding. When option two was exhausted, cattlemen weaned calves early and sold all calves not needed for replacement stock. Calf sales due to a forage deficit were permitted only in the two months prior to the weaning date of each calving system (spring herd — August and September; fall herd — April and May). Early

weaning had the effect of reducing forage demand by removing calf consumption and eliminating cow requirements for lactation. If the forage deficit remained, the cow herd was reduced by selling open or dry cows first, and then cow-calf pairs (if weaning had not occurred) until the deficit was alleviated. Herd reduction was the last resort because of the significant expense involved with restocking. If herd size was reduced, enough heifers were retained at weaning to replenish the herd up to an annual maximum replacement rate of 25 percent of long-term herd size.

During the winter season (December through February), decisions were exercised in the following sequence:

1. feed hay from inventory
   - up to 100 percent of inventory

2. purchase and feed hay

Hay was fed from reserves until inventory was depleted, and then purchased to meet remaining requirements. Stocking level was not reduced during this time.

The criterion used to initiate short-term decisions is explained in the next section. Hay diversions, feeding, and stocking adjustments impact the ration available for animals in each month. Ultimately, these impacts determine animal performance.

Cattle Parameters

Interaction among the forage, cattle, and managerial parameters defined the ration fed to each class of cattle (Figure 2). The available ration included the quantity and quality of both grazed pasture and hay. Using these variables, monthly animal performance for each class of cattle was developed.

Ration Parameters. The monthly ration fed each class of cattle was described by two parameters: quantity and quality. Ration quantity was defined as the amount of grazed pasture and hay fed in a month. The quality of ration was determined by an average of the quality of each feed source (pasture and hay), weighted by the amount each contributed to the total ration.

Monthly ration quantity was specified by dividing the amount of forage designated for herd grazing in each month among the animal classifications. Forage was allocated to each class according to an estimate of their respective monthly intakes. Such a procedure was designed to incorporate competitive and dynamic relationships existing among grazing cattle due to the changing forage demands of growing animals.

The voluntary intake of cattle has been shown to be an increasing function of forage quality for rations containing less than 67 percent total digestible nutrients (Conrad et al., 1966) and a decreasing function of quality for rations with a TDN percent of 67 or greater (Dinius et al., 1976). Using these intake relations, along with the quality of grazing forage, daily voluntary intake of cattle in each month was determined from;

(4)
$$DVI_{i,t} = \frac{0.0107\ EW_{i,t-1}}{[\,1 - (GQ_t / 100)\,]} \quad \text{if } GQ_t \le 66, \text{ and}$$

$$DVI_{i,t} = [\,.061742 - .00045866\ GQ_t\,]\ EW_{i,t-1} \quad \text{if } GQ_t > 66^2$$

where:

$DVI_{i,t}$ = daily voluntary intake (lbs. DM per head) of animal class i during month t
$EW_{i,t-1}$ = animal weight (lbs.) maintained by animal class i at the end of month t-1 (or beginning weight in month t)
GQ_t = grazing forage quality (% TDN) during month t
t = 1,...,12
i = 1,...,5

The animal assumed in this relation was a mature brood cow (1,000 pounds) in good condition. Any weight change during a month was assumed to reflect a condition change and did not affect intake capability. Bull weight (1,200 pounds) did not change during the year. As a calf matures, forage consumption makes up an increasing part of its diet. The intake of forage by a calf was determined using estimated calf weight at the beginning of each month. Heifers, like calves, consume a greater amount of forage with maturity. Estimated heifer weights beginning each month were used to specify monthly forage intake of weaned and replacement heifers. The relative intake of each animal class was used to allocate the estimated total available grazing forage by the equation;

(5)
$$DAGFi,t = (TAGF_t * INPER_{i,t}) / HEAD_{i,t} / DAYS_{i,t}$$

with:

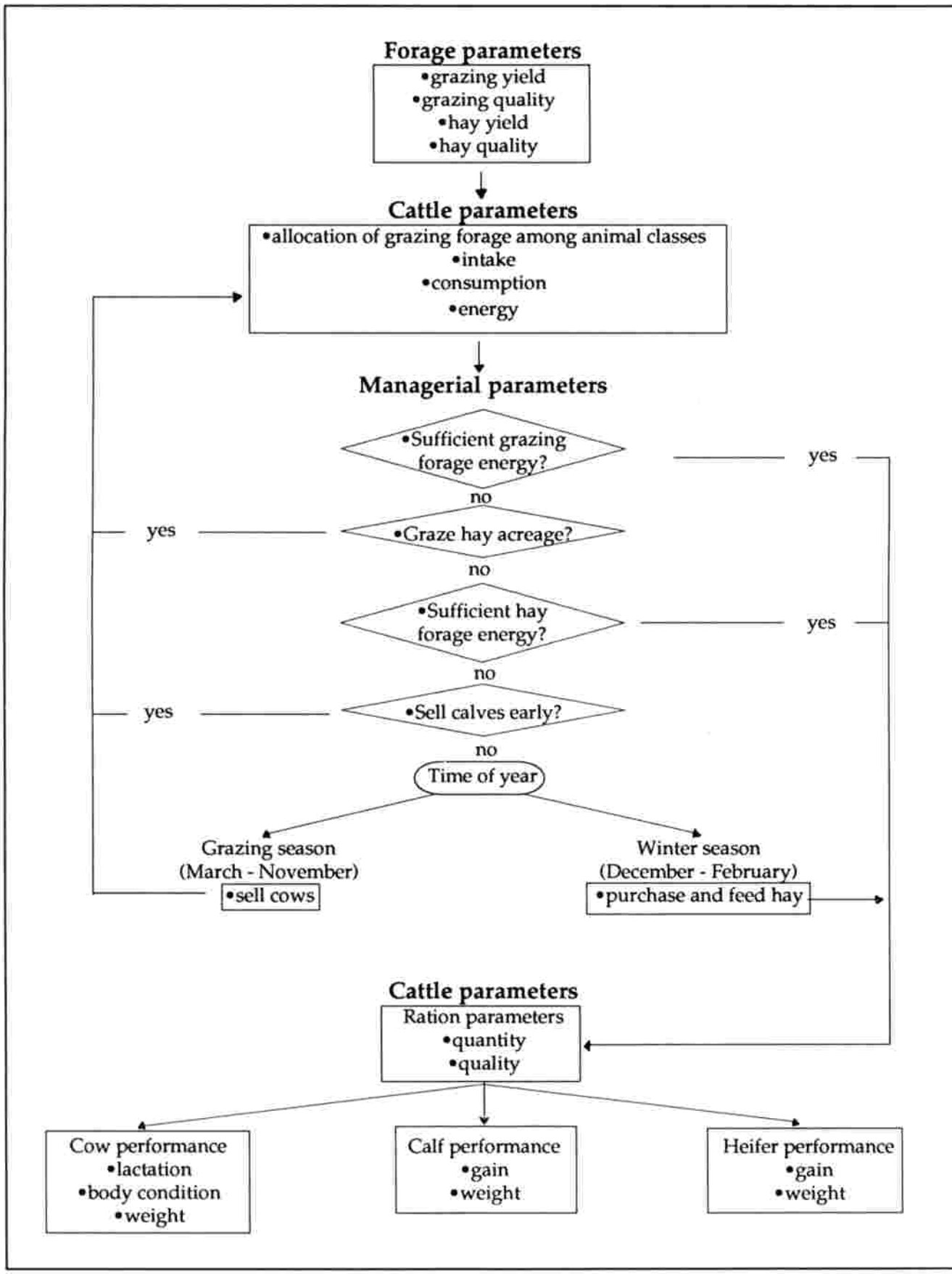


Figure 2. Schematic of the interaction among forage, cattle, and managerial parameters to determine monthly ration parameters and animal performance.

(6) $INPER_{i,t} = DVI_{i,t} / TDVI_t$

where:

$DAGF_{i,t}$ = daily available grazing forage (lbs. DM per head) for animal class i during month t
$TAGF_t$ = estimated total available grazing forage (lbs. DM) during month t
$INPER_{i,t}$ = the percentage of total intake attributed to animal class i during month t
$HEAD_{i,t}$ = number of head stocked in animal class i during month t
$DAYS_{i,t}$ = number of days animal class i resides on the operation during month t
$TDVI_t$ = sum of daily intake levels for all animal classes in month t
t = 1,...,12
i = 1,...,5

The resulting estimate ($DAGF_{i,t}$) determined the maximum amount of available grazing forage for each class of cattle in a month. Estimated cattle consumption was constrained at the minimum of available grazing forage and intake capability ($DVI_{i,t}$).

Energy in the daily grazing forage consumption was described as a function of ration quality (see National Academy of Sciences, p. ix) by;

(7) $DCDE_{i,t} = 2.0041 [GQ_t / 100] [\min (DAGF_{i,t}, DVI_{i,t})]$

where:

$DCDE_{i,t}$ = daily available digestible energy (Mcal per head) for animal class i during month t

The net energy system (National Research Council) was used to describe energy available and required for maintenance (cows & bulls) and growth (calves & heifers). Daily available energy was converted to that available for animal maintenance and that for growth using the following conversion equations (National Research Council):

(8) $DME_{i,t} = 0.82 [DCDE_{i,t}]$

(9) $DNEM_t = 1.37 (DME_t) - 0.138 (DME_t)^2 + 0.0105 (DME_t)^3 - 1.12$

(10) $DNEG_t = 1.42 (DME_t) - 0.174 (DME_t)^2 + 0.0122 (DME_t)^3 - 1.65$

where:

$DME_{i,t}$ = daily available metabolizable energy (Mcal per head) for animal class i during month t
$DNEM_t$ = daily available net energy for cow and bull maintenance during month t
$DNEG_t$ = daily available net energy for calf and heifer growth during month t

Available energy was compared to minimum requirements of each animal class (see Table 6) for decision analysis. If grazing energy was sufficient to the meet minimum animal requirements, short-term decisions such as hay feeding were unnecessary; otherwise, short-term decisions were initiated. A deficit of energy during the haying seasons caused hay acreage to be diverted to grazing. In such cases, increments of 10 acres were diverted to grazing, with intake, consumption, and energy recomputed for each increment until enough energy was available to meet the minimum requirements or until the diversion limit was met. Hay was released from inventory within the seasonal feeding limits for animal classes still short of energy. Any remaining deficit was addressed by early calf sales permitted during specified months. If early weaning resulted, grazing forage was reallocated among the remaining animals. Finally, herd reductions were made during typical grazing season months (March through November) if necessary to alleviate any remaining deficit in forage energy. Cows were sold one at a time by selling open or dry cows first, then cow-calf pairs. Herd reduction continued until available grazing and hay forage energy were sufficient to meet the minimum requirements of the remaining herd. During the typical winter season (December through February), hay was purchased and fed when inventory levels were insufficient to satisfy herd requirements.

Minimum cow energy requirements were set differently for the typical grazing season (March through November) and winter months (December through February). During the grazing season, requirements included energy for body and gestation maintenance. Available energy above this minimum was used to determine cow lactation and body condition each month. During winter months, cows rely on hay as their primary feed source. Minimum energy requirements included energy for body and gestation maintenance in both herds and lactation in the appropriate months for each herd (see Table 6, footnote 1). Fall herd requirements included energy for lactation at a level to ensure fall-calving cows were fed enough winter hay to perform comparably with spring-calving cows during April, May, and June.

Table 6. Monthly net energy requirements per animal for maintenance and growth used to determine short-term decisions for spring- and fall-calving herds.

Month	Cows* (NEM)	Bulls (NEM)	Calves (NEG)	Weaned heifers (NEG)	Replacement heifers (NEG)
	Mcal per head per day*				
Spring herd					
January	13.40	8.73	0.00	1.87	5.39
February	11.11	8.73	0.00	2.10	5.65
March	7.61	8.73	0.00	2.31	0.00
April	7.61	8.73	0.00	2.55	0.00
May	7.61	8.73	0.00	2.79	3.46
June	7.62	8.73	0.00	0.00	3.61
July	7.64	8.73	0.35	0.00	3.84
August	7.72	8.73	0.74	0.00	4.10
September	7.95	8.73	1.11	0.00	4.35
October	8.52	8.73	1.43	0.00	4.61
November	9.62	8.73	0.00	1.46	4.86
December	11.35	8.73	0.00	1.65	5.12
Fall herd					
January	7.61	8.73	0.00	2.79	3.46
February	7.62	8.73	0.00	0.00	3.61
March	7.64	8.73	0.35	0.00	3.84
April	7.72	8.73	0.74	0.00	4.10
May	7.95	8.73	1.11	0.00	4.35
June	8.52	8.73	1.43	0.00	4.61
July	9.62	8.73	0.00	1.46	4.86
August	11.35	8.73	0.00	1.65	5.12
September	13.40	8.73	0.00	1.87	5.39
October	11.11	8.73	0.00	2.10	5.65
November	7.61	8.73	0.00	2.31	0.00
December	7.61	8.73	0.00	2.31	0.00

* Energy requirements for each class of cattle were based upon the following assumptions:

Cows — Requirements include energy for body maintenance (1,000 lbs) and gestation. Because hay is the primary feed source for cows during the winter season (December - February), additional requirements for lactation at an average level of 20 pounds of milk per head per day were included for the fall herd. Requirements for spring cow lactation were included for February at 9 pounds of milk per head per day. Thus, in the model, an additional 6.95, 7.02, and 6.45 mcal of NEM were added to the fall herd requirements in December, January, and February, respectively. An additional 3.07 mcal of NEM was added to spring herd requirements in February.

Table 6, continued.

Bulls — Requirements include energy for body maintenance (1,200 lbs).

Calves — Requirements include forage energy needed to supplement milk in the production of a 400 pound average weaned calf (320 lbs of gain for 274 days, or an average daily gain of 1.25 lbs). Calves were assumed to begin noticeable forage consumption at 6 weeks of age, although a minimum forage requirement was not specified until the calf reached 5.5 months of age.

Weaned heifers — Requirements include energy to produce a 660 pound heifer from weaning to breeding (215 lbs of gain for 196 days, or an average daily gain of 1.10 lbs).

Replacement heifers — Requirements include energy to produce an 850 pound heifer from breeding to calving (250 lbs gain for 274 days, or an average daily gain of 0.91 lbs).

** Energy requirements are expressed as the net energy required for maintenance (NEM) of cows and bulls, and net energy required for growth (NEG) of calves and heifers.

Source: National Research Council

To compensate for variations in body condition, monthly cow maintenance requirements were adjusted for condition (Klosterman) by adding

$$(11) \quad ADCOWR_t = [4.0 - [(CW_{t-1} / 2.2) / H]] * 1.716$$

where:

$ADCOWR_t$ = adjustment factor (positive or negative depending upon cow weight) for cow energy requirements (Mcal digestible energy per day) in month t

CW_{t-1} = cow weight at end of month t-1 (or beginning of month t)

H = 113.64; height (centimeters) at hooks of a 1,000- pound cow in good condition

2.2 = conversion factor for kilograms to pounds

to the minimum requirement. Thus, a cow carrying excess condition would have reduced requirements during that month. Conversely, cows in poor condition would have increased requirements.

Minimum energy requirements for bulls were set for maintenance at a body weight of 1,200 pounds. Calf and heifer requirements were set according to minimum performance standards. Calves required forage energy to achieve a minimum 400-pound average weaning weight for steers and heifers. Weaned heifer requirements were set to produce at least a 600-pound heifer at breeding. Replacement heifers required energy to achieve a minimum weight of 850 pounds at calving.

The ration fed to each animal class was the resulting combination of grazing and hay forage required to satisfy minimum monthly energy requirements. Available energy in the ration was utilized to determine performance of cows, calves, and heifers each month. Bull performance was assumed adequate.

Cow Performance. Cow weight and milk production in each month were determined by comparing available maintenance energy with required maintenance energy. At any time during the year, the cow was gestating, lactating, or both. Energy requirements reflected the unique maintenance needs of gestation and lactation during the appropriate months, along with body maintenance. Daily available and required maintenance energy were equated each month by

$$(12) \quad DNEM = DNEM_B + (DNEM_G / 1000) + DNEM_L$$

where:

$DNEM_B$ = daily required net energy for cow body maintenance (Mcal per head)
$= 0.0428\ W_t^{.75}$

$DNEM_G$ = daily required net energy for cow gestation maintenance (kcal per head)
$= CBW\ (0.0149 - 0.0000407d)e^{0.05883d - 0.0000804d2}$

$DNEM_L$ = daily required net energy for cow lactation (Mcal per head)
$= M_t [0.1 (F) + 0.35] / 2.2$

with:

W_t = intake cow weight (= 1,000 lbs.)
CBW = expected calf birth weight (= 80 lbs.)
d = day of gestation (requirement computed using the average for all days in a month)
e = 2.71828...
M_t = daily milk production (lbs. per head) during month t
F = percent fat content of milk (= 4)
2.2 = conversion factor for pounds to kilograms

Rearranging equation 12 to solve for milk production yields

$$(13) \qquad M_t = \frac{DNEM - DNEM_B - (DNEM_C / 1000)}{[\,0.1\,(F) + 0.35\,] / 2.2}$$

In this formulation, any excess or deficit energy is reflected in the level of milk production. However, actual milk production is closely related to milk demand. The level of daily milk production during a month was therefore constrained by upper and lower bounds, defined as maximum and minimum milk intake levels. Comparing the estimate of milk production derived from equation 13 to the bounds, three cases were possible:

(case 1) $M^{max} \geq M_t \geq M_{min}$
(case 2) $M_t > M^{max}$
(case 3) $M_t < M_{min}$

If case 1 resulted, the milk level defined by equation 13 was used and the amount of available energy was sufficient to meet required energy. If either case 2 or case 3 were observed, Mmax or Mmin was used to describe milk production during the month. In these instances, a surplus of energy (case 2) or a deficit of energy (case 3) existed. The amount of surplus or deficit energy was determined, using the estimated milk intake, by

$$(14) \qquad EXNE_t = DNEM - DNEM_B - (DNEM_C / 1000) - DNEM_L$$

where:

$EXNE_t$ = surplus (>0) or deficit (<0) net energy (Mcal per head) during month t

Holloway et al. (1983) estimated lactation curves from calf milk intake, for beef cows grazing tall fescue pastures in Tennessee. Maximum and minimum lactation bounds were specified in each month according to these results. The equation used to determine average monthly milk production was

$$(15) \qquad M_t = 1.6764d^{0.828}e^{-0.0115d}$$

where:

Mt = estimated milk production in month t (pounds of milk per day)
d = day of lactation in month t
e = 2.71828... .

Holloway et al. (1983) reported milk intake estimates at 30-day intervals during lactation, along with variances of each estimate. Maximum monthly lactation bounds were specified using the average milk intake estimates in each month from equation 15, plus one standard deviation of the estimates. Likewise, minimum monthly lactation bounds were set by deducting one standard deviation from the monthly estimates. Average monthly lactation levels and bounds for the spring- and fall-calving herds are presented in Table 7.

Any surplus or deficit net energy in a month was assumed to be reflected in cow performance by changes in body condition. Klosterman et al. established a relationship between the height at hooks and the weight of a cow that can be used to adjust energy requirements for cows in different condition. The average weight (kg) to height (cm) ratio for a cow in good condition is 4.0:1. The adjustment in energy required by mature cows in different condition was determined to be

$$(16) \qquad ADER = 1.716\ (4.0 - W / H)$$

where:

ADER = the adjusted amount of energy required (Mcal DE per head)
W = cow weight (kg)
H = cow height at hooks (cm).

This relationship was modified to estimate cow weight change in relation to surplus or deficit energy in a month. For any weight level describing a cow in good condition, the height at hooks is determined using the weight to height ratio of 4.0:1. Thus, a 1,000-pound cow in good condition would measure 113.64 centimeters at hooks. Rearranging equation 16 and substituting the surplus or deficit energy for the adjusted requirement, the equation used to estimate weight change in a month was

$$(17) \qquad WC_t = 2.2\ [\,(6.864 \pm EXNE_t)\ GCH / 1.716\,] - GCW$$

Table 7. Monthly lactation bounds used to specify milk production for spring- and fall-calving herds.

Month	Spring herd			Fall herd		
	Average*	Maximum	Minimum	Average	Maximum	Minimum
	lbs milk per head per day**					
January	—	—	—	19.60	23.39	15.82
February	7.74	10.71	4.77	17.78	21.32	14.23
March	15.62	18.59	12.65	15.25	18.68	11.95
April	19.67	23.58	15.75	12.80	16.15	9.46
May	19.60	23.39	15.82	10.49	13.93	7.06
June	17.78	21.32	14.23	8.49	12.10	4.88
July	15.25	18.68	11.90	—	—	—
August	12.80	16.15	9.46	—	—	—
September	10.49	13.93	7.06	—	—	—
October	8.49	12.10	4.88	7.74	10.71	4.77
November	—	—	—	15.62	18.59	12.65
December	—	—	—	19.67	23.58	15.75

* Average daily milk production levels were developed in each month from equation 15. Maximum and minimum bounds were set at one standard deviation above and below, respectively, the average milk estimate in each month.

** Dashes indicate months in which cows are dry.

Source: Adapted from Holloway (1983).

where:

WC_t = weight change (lbs) during month t
GCW = weight (lbs) of a cow in good condition (= 1,000 lbs)
GCH = height (cm) of a cow in good condition (= 113.64 cm)
2.2 = the conversion factor for kilograms to pounds.

If a surplus existed, the amount of the surplus was added in equation 17. Likewise, an energy deficit was subtracted in equation 17. The resulting weight change was used to develop cow weight at the end of each month by

(18) $ECW_t = BCW_t + WC_t$

where:

ECW_t = ending cow weight (lbs) in month t
BCW_t = beginning cow weight (lbs) in month t.

This weight estimate was used to adjust cow energy requirements in subsequent months and for cows sold because of culling and stocking adjustments during the relevant months.

Calf Performance. Calf weight and growth were developed for each month. The calf consumed milk and forage and thus obtained energy from both feed sources. Available growth energy from milk was defined by

(19) milk DNEG = 0.55 [M_t]

where:

milk DNEG = daily net energy available from milk (Mcal per head) for growth
0.55 = net energy available per pound of fresh milk (Mcal per head) (National Academy of Sciences).

Thus, total energy for calf growth was specified as

(20) DNEG = milk DNEG + forage DNEG

where:

DNEG = daily net energy (Mcal per head) available for growth.

Using the estimate of available growth energy, along with calf weight beginning each month, average daily gain (pounds per day) was expressed for steer and heifer calves each month as

(21) $ADSCG_t = [\ 32.316\ (DNEG / BSCFW_t^{.75})\ ]^{0.911577}$

(22) $ADHCG_t = [\ 26.239\ (DNEG / BHCFW_t^{.75})]^{0.893655}$

where:

$ADSCG_t$ = average daily steer calf gain (lbs per day) during month t
$ADHCG_t$ = average daily heifer calf gain (lbs per day) during month t
$BSCFW_t$ = beginning steer calf weight (lbs) in month t
$BHCFW_t$ = beginning heifer calf weight (lbs) in month t.

Average daily gain is the rate at which calves grew during a month. Steer and heifer weight estimates at the end of each month were calculated using beginning calf weight, daily gain, and length of time calves were retained each month by

(23) $ESCFW_t = [\ (ADSCG_t)\ (DAYS_t)\ ] + BSCFW_t$

(24) $EHCFW_t = [\ (ADHCG_t)\ (DAYS_t)\ ] + BHCFW_t$

where:

$ESCFW_t$ = ending steer calf weight (lbs) in month t
$EHCFW_t$ = ending heifer calf weight (lbs) in month t
$DAYS_t$ = number of days calf resides on the operation in month t.

These estimates were used to specify calf weights at weaning, plus intake, consumption, energy and performance variables in the next month.

Heifer Performance. Weaned and replacement heifer growth and weight were also determined in each month. Heifers utilized available forage energy for weight gain. Average daily gain (pounds per day) was developed each month for both heifer categories with the equation

(25) $ADHG_t = [\ 26.239\ (DNEG / BHW_t^{.75})\ ]^{0.893655}$

where:

$ADHG_t$ = average daily weaned and replacement heifer gains (lbs per day) during month t
BHW_t = beginning weaned and replacement heifer weights in month t.

Thus, ending weaned and replacement heifer weights each month were specified as

(26) $EHCFW_t = [\ (ADHCG_t)\ (DAYS_t)\ ] + BHCFW_t$

where:

EHW_t = ending weaned and replacement heifer weights in month t
$DAYS_t$ = number of days weaned and replacement heifers resided on the operation in month t.

Like calf weights, ending heifer weights were used to specify ration and performance variables in subsequent months.

Price and Cost Parameters

Price and cost parameters were specified to describe the economic environment confronted by cattlemen. As with physical forces, economic conditions fluctuate. These fluctuations have important implications for the profitability of cattle production. Consequently, an attempt was made to project price and cost variability over the 10-year planning span.

Cattle and Hay Price Estimation. An accurate forecast of livestock prices over the 10-year span was not possible; however, a representation of historical price variability was feasible. This was accomplished by forecasting cyclical price movements from historical data. While turning points of price cycles were too erratic to precisely forecast, a stochastic simulation of the expected cattle cycle offered a reasonable representation of possible future trends.

Harmonic regressions were used to project a potential path for the cattle cycle (Franzmann and Walker; Gutierrez; VanTassell). Ordinary least-squares equations estimated for cattle prices using the following cyclical trend model are displayed in Table 8;

(27) $P_{t1} = \beta_0 + \beta_1\ 2\pi t + \beta_2\ SIN(2\pi t / L1) + \beta_3\ COS(2\pi t / L1) + \beta_4\ SIN(2\pi t / L2) + \beta_5\ COS(2\pi t / L2) + \varepsilon$

where:

$P_{i,t}$ = predicted price for cattle price class i in month t
L1 = seasonal component (= 12 months)
L2 = cyclical component (= 120 months)
β_k = parameter estimates (k = 1,...,5)
$2\pi t$ = time trend component (π = 3.1415927)
SIN & COS = sine and cosine of variables to specify magnitude and frequency of seasonal and cyclical components.

Following Franzmann and Walker, a 12-month seasonal component was specified for L1, and a 120-month cycle for L2. Steer, heifer, and utility cow equations were estimated using monthly price data for 1972 through 1987. Prices were developed for 300-400, 400-500, 500-600, and 600-700 pound steer and heifer calves. Steer and heifer prices were then linearly interpolated according to their resulting weights in months of weaning.

Table 8. Cattle price ordinary least-squares equations for the cyclical trend model.

Steer prices[a]

ST34 = 44.14 + 0.037T + 2.323S1 - 1.607C1 - 14.886S2 + 9.919C2 + ε
(24.1)** (14.4)** (1.9)* (-1.3) (-11.2)** (7.9)**

R^2 = 0.67 STD DEV = 12.21 N = 192

ST45 = 41.83 + 0.033T + 1.999S1 - 1.442C1 - 12.821S2 + 8.833C2 + ε
(27.7)** (15.5)** (1.9)* (-1.4) (-11.7)** (8.5)**

R^2 = 0.69 STD DEV = 10.08 N = 192

ST56 = 39.64 + 0.031T + 1.228S1 - 1.286C1 - 10.890S2 + 8.172C2 + ε
(31.5)** (17.4)** (1.5) (-1.5) (-11.9)** (9.4)**

R^2 = 0.73 STD DEV = 8.41 N = 192

ST67 = 37.95 + 0.029T + 0.812S1 - 0.915C1 - 9.499S2 + 7.724C2 + ε
(35.3)** (18.8)** (1.1) (-1.2) (-12.2)** (10.4)**

R^2 = 0.75 STD DEV = 7.19 N = 192

Heifer prices

HF34 = 36.32 + 0.030T + 2.079S1 - 2.124C1 - 12.387S2 + 7.724C2 + ε
(23.9)** (13.7)** (2.0)** (-2.0)** (-11.2)** (8.4)**

R^2 = 0.66 STD DEV = 10.16 N = 192

HF45 = 34.71 + 0.029T + 1.743S1 - 1.745C1 - 11.144S2 + 7.886C2 + ε
(25.9)** (15.0)** (1.9)* (-1.9)* (-11.4)** (8.5)**

R^2 = 0.69 STD DEV = 8.97 N = 192

HF56 = 33.01 = 0.028T + 1.186S1 - 1.328C1 - 9.707S2 + 7.548C2 + ε
(28.3)** (16.7)** (1.5) (-1.7)* (-11.5)** (9.4)**

R^2 = 0.72 STD DEV = 7.80 N = 192

Table 8, continued.

Heifer prices, continued

$$HF67 = 32.72 + 0.062T + 1.053S1 - 1.390C1 - 9.536S2 + 6.852C2 + \varepsilon$$
$$(29.7)^{**}\ (16.4)^{**}\ (1.4)\ (-1.8)^{*}\ (-11.9)^{**}\ (9.0)^{**}$$

$R^2 = 0.72$ STD DEV = 7.37 N = 192

Utility cow price

$$UTCOW = 26.68 + 0.016T = 1.620S1 - 1.411C1 - 6.468S2 + 5.348C2 + \varepsilon$$
$$(39.0)^{**}\ (16.8)^{**}\ (3.5)^{**}\ (-3.0)^{**}\ (-13.0)^{**}\ (11.4)^{**}$$

$R^2 = 0.75$ STD DEV = 4.58 N = 192

Replacement bull and cow-calf pair prices[b]

$$RBULL = 813.3 + 1.1T + 160.8S1 - 117.0C1 - 38.5S2 + 159.5C2 + \varepsilon$$
$$(11.2)^{**}\ (9.4)^{**}\ (3.2)^{**}\ (-2.3)^{**}\ (-0.8)\ (3.1)^{**}$$

$R^2 = 0.43$ STD DEV = 454.57 N = 168

$$CWCF = 348.25 + 0.27T + 5.22S1 - 21.16C1 - 93.73S2 + 108.62C2 + \varepsilon$$
$$(24.2)^{**}\ (11.6)^{**}\ (0.5)\ (-2.1)^{**}\ (-9.3)^{**}\ (10.5)^{**}$$

$R^2 = 0.68$ STD DEV = 90.10 N = 168

Hay price

$$HAY = 35.21 + 0.019T + 0.840S1 + 0.315C1 - 2.512S2 - 2.891C2 + \varepsilon$$
$$(67.9)^{**}\ (25.2)^{**}\ (2.4)^{**}\ (0.9)\ (-6.7)^{**}\ (-8.1)^{**}$$

$R^2 = 0.83$ STD DEV = 3.47 N = 192

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[a] t-values for each parameter are in parentheses below parameter estimate.

[b] Obtained from VanTassell.

* Significant at the 90-percent level.

** Significant at the 95-percent level.

where:

STD DEV = standard deviation
N = number of observations
ST34, ST45, ST56, and ST67 = per cwt. steer prices for 300-400, 400-500, 500-600, and 600-700 pound steer calves, respectively
HF34, HF45, HF56, and HF67 = per cwt. heifer prices for 300-400, 400-500, 500-600, and 600-700 pound heifer calves, respectively

Table 8, continued.

UTCOW	= per cwt. utility cow price
RBULL	= per cwt. replacement bull price
CWCF	= per head cow-calf pair price
T	= 2 t
S1	= SIN (2πt/L1)
C1	= COS (πt/L1)
S2	= SIN (2πt/L2)
C2	= COS (πt/L2)
L1	= cycle length of 12 months
L2	= cycle length of 120 months
ε	= residual error term

Price data were collected from reports of Tennessee feeder calf auction prices (Tennessee Agricultural Statistics) for medium-frame choice steer and heifer calves, and utility cows. Bulls and cow-calf pairs sold because of stocking reductions were priced according to estimates made by VanTassell. Slaughter bull prices were estimated at approximately 1.25 times utility cow prices. Replacement bull prices were obtained from auction summary reports for registered Hereford bulls (American Hereford Journal). Cow-calf pair prices were obtained for young to middle aged, medium- to large-framed, #1 to #2 cows with baby to 300-pound calves at side, reported from North Central Texas Auction markets (Texas Department of Agriculture, 1972-85).

The possibility existed that cattlemen would purchase or sell hay during a year. Monthly hay prices received by farmers during the 1972-87 period (Tennessee Agricultural Statistics) were related to the cattle cycle. Hay prices closely followed the price cycle, reaching cyclical turning points approximately 3 years before those of the cattle cycle. The estimated equation for hay selling price is included in Table 8. The October price forecast was used during years in which hay was sold. Hay purchased was levied an additional $3.00 per ton charge for hauling.

The prediction equations were stochastically simulated using correlated random normal deviates developed from the covariance matrix of harmonic function residuals. The cattle cycle was initiated in 1988 and forecasted over the 10-year span of 1989 through 1998. Cattle and hay prices were simulated over the 10-year planning horizon for 100 iterations.

Price and Cost Levels. Inflation and interest rates were assumed to follow projected levels for each year of the 10-year planning span (1989-98). Estimates reported by the Food and Agricultural Policy Research Institute were used to specify assumed annual inflation and interest rates. Annual inflation and interest rate projections for each of the ten years are shown in Table 9. Inflation levels were specified by expense categories using forecasts of prices paid by farmers for different expense items.

Cattle and hay price trends also followed the assumed economic environment for 1989 through 1998. Price projections using the estimated equations were detrended and inflated according to inflation forecasts in each year. Annual cattle and hay price levels were developed using aggregate GDP deflator forecasts, and a 0.725 transmission coefficient between inflation rates and farm input and output prices (Tweeten). These estimates are also presented in Table 9.

Budgetary Parameters

Annual financial characteristics of the cattle operation were summarized using a budgetary framework. Annual biological and economic parameters were combined to determine resultant budgetary variables for each of the ten years. The budgets included annual gross receipts, operating and fixed expenses, and tax accounting of the cattle enterprise. Ultimately, net returns to various sets of fixed resources were computed. An outline of the various return and expense categories and items in each category is shown in Table 10.

Gross Receipts. Annual gross receipts included cattle and hay sales. Prices prevailing in selling months of each receipt item were used as the per unit price received. Steer and heifer prices were further assigned according to their respective selling weights. The number of head or tons of hay sold each month was used to compute annual gross receipts from each item.

Table 9. Annual interest and inflation rates for 1989 - 1998.

Item	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998*
Annual interest rates**										
Int.-term	10.7	10.6	10.5	10.4	10.6	10.9	11.5	12.1	12.7	13.4
Operating	12.8	12.7	12.6	12.5	12.7	13.1	13.8	14.6	15.3	16.1
Annual percentage change in price										
Cattle and hay	2.9	3.0	2.5	2.5	2.6	2.8	3.2	3.3	3.6	3.6
Seed	3.1	3.6	3.0	3.0	3.3	4.0	4.5	5.8	5.9	5.9
Fertilizer	6.4	4.6	3.5	4.4	4.5	4.8	5.0	5.7	7.1	7.1
Chemicals	4.0	2.9	3.2	2.9	3.0	3.2	3.4	3.9	5.0	5.0
Farm services	5.3	-2.4	1.4	2.3	2.9	3.7	4.0	4.7	4.9	4.9
Fuel and lube	5.3	2.5	3.5	5.0	5.0	8.7	6.6	6.8	4.7	4.7
Repairs	2.5	2.6	3.7	4.2	4.4	4.8	5.1	5.2	5.5	5.5
Machinery	6.7	4.4	4.4	5.1	6.2	5.7	6.2	6.1	7.4	7.4
Insurance and taxes	4.1	1.8	2.1	2.9	3.3	5.0	4.8	5.2	5.4	5.4
Labor	4.7	5.0	5.2	5.2	5.0	5.4	5.8	6.1	6.5	6.5
Other inputs	4.3	1.8	2.0	2.9	3.2	5.1	4.6	5.1	5.3	5.3

* Because 1998 projections were not available, 1997 levels were assumed to prevail in 1998.

** Interest rates charged each year on intermediate-term loans and short-term operating loans.

Source: Food and Agricultural Policy Research Institute and the Federal Reserve System.

Operating Expenses. Annual operating expenses included pasture, hay, cattle, labor, and operating capital costs. Pasture costs were separated into those for establishment and annual maintenance. Major expense items in each category included seed, fertilizer, and variable machinery costs. Items were charged to the production systems by the amounts used in each system. Annual per-acre costs were combined with the number of acres established and maintained each year to compute total annual pasture costs. Like pasture costs, operating expenses for hay production were charged on the number of acres actually harvested in each production system. Purchased hay was charged the prevailing hay price according to the amount used in months that extra hay was needed, plus a per-ton hauling charge.

Annual operating expenses for cattle included salt and mineral, medical, marketing, bull replacement, and variable machinery and equipment costs. Annual cattle costs accrued according to the number of head actually maintained on the operation during the year. Bull replacements were charged the prevailing market price in months prior to breeding when bulls were acquired. Machinery and equipment variable expenses were set according to annual machinery and equipment usage.

Labor expenses incurred each year included only labor required above the supply available to the cattle operation. Purchased labor was acquired in the amount and during the months needed at an hourly rate. Operating capital charges were set according to the annual operating expenses, using the prevailing interest rate for operating loans.

Fixed Expenses. Annual fixed expenses included fixed machinery and equipment costs associated with pasture, hay, and cattle production. Fixed costs of machinery and equipment items were depreciation,

Table 10. Budgetary parameters.

Gross receipts

A. Cattle sales
   1. Steer calves
   2. Heifer calves
   3. Non-breeding heifers
   4. Culled cows
   5. Aged bulls
   6. Cow-calf pairs

B. Hay sales

Operating expenses

A. Pasture costs
   1. Establishment costs
      a. Seed (sprigs)
      b. Fertilizer and lime
      c. Machinery repairs, fuel, and lubrication
   2. Annual costs
      a. Fertilizer
      b. Machinery repairs, fuel, and lubrication

B. Hay costs
   1. Production
      a. Twine
      b. Machinery repairs, fuel, and lubrication
   2. Purchased hay

C. Cattle costs
   1. Salt and minerals
   2. Veterinary/medicine
   3. Marketing
   4. Bull replacement
   5. Machinery repairs, fuel, and lubrication
   6. Equipment repairs

D. Labor costs
   1. Purchased labor

E. Operating capital costs

Fixed expenses[a]

A. Pasture costs
   1. Machinery depreciation, interest, and insurance

B. Hay costs
   1. Machinery depreciation, interest, and insurance

C. Cattle costs
   1. Machinery depreciation, interest, and insurance
   2. Equipment depreciation, interest, and insurance

Net returns

A. Returns above operating expenses
B. Returns above operating and fixed expenses

Tax accounting

A. Machinery, equipment, and bull depreciation deductions
B. Taxes on returns above fixed and operating expenses

After-tax net returns

A. Annual returns above fixed, operating, and tax expenses

[a] Fixed expenses were charged at the rate machinery and equipment items were used in each production system.

interest, insurance, and property taxes. A straight-line schedule was used to depreciate each item over its economic life. Interest charges were based upon the average amount of capital invested during the ownership period and were calculated using the annual prevailing interest rate for intermediate-term loans. Insurance costs were also computed on the average capital invested using the prevailing insurance rate.

Total annual fixed costs included the sum of depreciation, interest, and insurance for each of the machinery and equipment categories. Fixed costs were charged according to annual usage rates of machinery and equipment items by each production system. Full ownership of livestock was assumed. Replacement heifers were used to replenish the cow herd each year. Investments in land and the cow herd and resident labor supply were considered as an initial unit of owned and operator contributed resources and were not charged in net returns calculations.

Net Returns and Tax Accounting. Annual net returns from the cattle operation were determined by deducting the relevant expense items from gross receipts. Returns above the specified operating expenses and returns above the specified operating and fixed expenses were summarized each year.

Accounting measures for the cattle operation were developed so that tax liability could be properly handled. For income tax purposes, the depreciation accruing each year for machinery, equipment, and bulls was calculated. Machinery and equipment tax depreciation was specified as 7-year property, while bulls had a 5-year recovery period. Depreciation was spread over the years using a straight-line schedule. Annual machinery, equipment, and bull depreciation were used as a tax deduction, and net returns above operating and fixed expenses were adjusted accordingly. Taxes were charged on returns above operating and fixed expenses according to the relevant tax bracket. Returns below $29,750 were taxed at a 15 percent marginal tax rate, and tax charges on net returns above this level were at a 28 percent marginal rate (Internal Revenue Service). After-tax net returns above the specified operating and fixed costs were summarized for each year of the 10-year span.

Model Results

The simulation model was developed to examine the effect of uncertain conditions upon biological and economic performance of a cattle operation in West Tennessee. To obtain a representative sampling of the stochastic processes inherent in the model, a 10-year planning horizon was simulated for 100 iterations. Four production systems were specified, including the combination of tall fescue and bermudagrass/tall fescue pasture systems with spring- and fall-calving beef herds. To facilitate the following discussions the production systems were designated as TFSC and TFFC for the tall fescue forage system with spring- and fall-calving herds, respectively, and BFSC and BFFC for the bermudagrass/tall fescue system with spring and fall herds, respectively.

Model capabilities for replicating characteristics of forage-beef systems were examined in each of three respects. The forage systems were evaluated by yield variables in addition to hay system performance and management variables. Animal performance in spring- and fall-calving herds on each forage system were then compared. Cattle variables, including herd numbers, sales, and animal weights, were examined. Ultimately, financial characteristics of the cattle operation were evaluated. Receipts, expenses, and three measures of net returns were compared. Because the 10-year planning span was simulated 100 times for each alternative, the annual summary statistics were developed from 1,000 years of observations.

Forage System Performance

Selected annual forage system performance statistics for the cattle operation are shown in Table 11. Annual forage yield was the amount of forage growth (lbs dry matter) accumulated each year from January 1 through December 31. Mean yield in the grass systems was lower for the tall fescue forage (5,827.64 lbs DM per acre) than the bermudagrass/tall fescue mixture (6,233.46 lbs DM per acre). Yield variability was greater for tall fescue. However, neither system exhibited substantial variations in forage yield.

Acreage used for hay production in each system was set by the long-term decision component of the model. Variations from this level represented acreage adjustments necessary to compensate for poor forage production. Forage production during April through June was always adequate so that grazing of hay acreage was not necessary. All acreage idled for first cutting hay in each forage system was therefore harvested. However, at the second cutting of hay, acreage adjustments were required in some instances. Production systems using fall calving grazed a portion of acreage idled for hay during July through September in low yield years. These adjustments were small, with no more than 10 acres diverted to grazing in any year.

Mean hay yields at each cutting followed much the same pattern across systems as forage yields. At both cuttings, hay yields were highest for the bermudagrass/tall fescue forage. Variations in

Table 11. Selected forage system annual performance statistics for the cattle operation under each forage system with spring- and fall-calving systems.*

Variable	Forage and calving systems**			
	TFSC	TFFC	BFSC	BFFC
Forage production**				
Forage yield (lbs DM per acre)****				
Mean	5827.64		6233.46	
Standard deviation	145.12		100.04	
Minimum	5295.86		5911.00	
Maximum	6216.25		6506.07	
Hay production (first cutting)				
Hay acreage (acres)				
Mean	70.00	50.00	50.00	40.00
Standard deviation	0.00	0.00	0.00	0.00
Minimum	70.00	50.00	50.00	40.00
Maximum	70.00	50.00	50.00	40.00
Hay yield (tons per acre)				
Mean	1.43	1.51	1.68	1.77
Standard deviation	0.06	0.07	0.05	0.05
Minimum	1.23	1.30	1.53	1.61
Maximum	2.64	1.73	1.85	1.95
Hay production (second cutting)				
Hay acreage (acres)				
Mean	0.00	28.90	20.00	38.31
Standard deviation	0.00	3.03	0.00	3.75
Minimum	0.00	20.00	20.00	30.00
Maximum	0.00	30.00	20.00	40.00
Hay yield (tons per acre)				
Mean	0.00	1.40	1.64	1.90
Standard deviation	0.00	0.06	0.08	0.06
Minimum	0.00	1.19	1.12	1.69
Maximum	0.00	1.65	1.88	2.08

Table 11, continued.

Variable	Forage and calving systems**			
	TFSC	TFFC	BFSC	BFFC
Hay management				
Hay fed (tons)				
Mean	58.74	82.52	79.73	110.11
Standard deviation	0.74	0.86	0.71	1.08
Minimum	56.39	79.67	78.35	105.02
Maximum	61.00	85.36	82.91	113.57
Hay purchased and fed (tons)				
Mean	0.00	0.10	4.35	2.51
Standard deviation	0.00	0.73	1.57	2.06
Minimum	0.00	0.00	0.00	0.00
Maximum	0.00	9.20	6.79	12.25
Hay sold (tons)				
Mean	14.42	4.67	10.34	0.07
Standard deviation	3.67	3.12	2.73	0.36
Minimum	2.14	0.00	0.00	0.00
Maximum	26.13	15.13	21.95	3.55

* The statistics presented in this table were based upon annual measurements of each variable for 100 iterations of 10 years. Thus, statistics were based upon a sample size of 1,000 observations.

** The forage and calving systems are: TFSC = tall fescue and spring calving; TFFC = tall fescue and fall calving; BSFC = bermudagrass/tall fescue and spring calving; and BFFC = bermudagrass/tall fescue and fall calving.

*** Statistics are identical for the forage systems with both calving herds because annual forage production in independent of the calving system utilized.

**** Reported yields are prior to the 10 percent deduction for grazing and hay harvesting losses.

hay yields at each cutting were only slight.

Hay fed, purchased, and sold were summarized to describe hay management on the cattle operation. Mean hay fed was the average annual tonnage fed from farm inventory. The bermudagrass/tall fescue forage supported larger herds, and thus generally required more hay than the tall fescue forage. Fall herds required more than 20 tons more hay annually than the spring herds with each forage system. Variability in the hay feeding level was much greater in the fall-calving systems, although none of the systems experienced substantial variability.

Purchased hay was used during winters in which hay supplies were inadequate. Mean hay purchased was the annual average tonnage purchased and fed. Little hay above farm inventory was required. Fall-calving systems required more extra hay than spring-calving systems. These systems were also more variable in the amount of hay required.

Annual average tonnage of hay sold was measured as the mean amount of hay sold in October of each year. The operator sold excess hay production during a year if the October inventory was above the average in a normal year, plus a 10-percent

buffer. Spring-calving systems sold more and purchased less hay than their counterpart fall-calving systems. This same relationship held for variations in amounts of hay purchased and sold each year.

Cattle System Performance

Cattle system performance variables are summarized in Table 12. Annual herd size was the number of cows maintained on the cattle operation prior to weaning and culling each year. Long-term herd size was set by the decision component of the model. The cattle operation was not allowed to purchase additional cows in response to changing conditions, thus variations from the long-term herd size would have been due to reduced stocking. Resulting herd size, however, remained constant in every year simulated. As simulated, forage conditions were never severe enough to cause stocking reductions.

Weight and milk production were used to summarize annual performance of cows. Mean cow weight was the annual average weight (pounds) of each month. A 1,000-pound weight was used to describe a cow in good body condition. Weight variations above and below 1,000 pounds represented body condition changes. Annual mean cow weight in the production systems ranged from 1,087.0 (BFSC) to 1,172.6 (TFFC) pounds, indicating cows retained excess condition. Cows in the fall-calving systems were somewhat heavier than spring-calving cows and exhibited less weight variability. Cows grazing the bermudagrass/tall fescue forage exhibited wider variations in weight, and thus condition, than cows grazing the tall fescue forage.

Mean cow milk production was the annual average milk production (pounds of milk per day) in each month that cows were lactating. Spring-calving cows performed better than fall-calving cows during lactation as indicated by the milk estimates. Also, lactation was generally superior for cows grazing the tall fescue forage as compared to the bermudagrass/tall fescue forage.

Statistics on weaning weights were summarized for both steer and heifer calves. Mean steer and heifer calf weaning weights were the annual average weights observed in the respective weaning months of the spring and fall herds. Among the production systems, mean weaning weights ranged from 470.1 (BFFC) to 544.1 (TFSC) pounds for steer calves, and from 401.0 (BFFC) to 460.6 (TFSC) pounds for heifer calves. Spring-born calves were weaned at a heavier weight than fall-born calves. Spring herd weaning weights were more variable than those of the fall herd, although weight variability was not substantial with either herd. Much higher weights were obtained with the tall fescue forage versus the bermudagrass/tall fescue forage.

Two weight measurements were taken for replacement heifers. Mean replacement heifer breeding weight was the average annual weight achieved by weaned heifers at breeding. To obtain a high conception rate and to ensure that heifers are big enough at calving, Cook recommends that heifers weigh 600-650 pounds before being bred. Generally, breeding weights within or above this recommended range were achieved. However, average weight in the BFSC system fell short of the 600 pound minimum weight at 568.5. In contrast to calf weaning weights, heifer breeding weights were generally higher in fall- than in spring-calving systems.

Once bred, heifers should be fed to achieve 900-950 pounds of weight at calving (Cook). Each production system was on the average, near, at, or above this weight goal. Mean heifer calving weight measured the annual average weight of replacement heifers at calving. Weight comparisons were very similar to those of breeding weight among the systems. Fall-calving heifers generally weighed more than spring-calving heifers when calving. Heifers grazing tall fescue pastures were heavier at calving than those grazing bermudagrass/tall fescue pastures.

Financial Characteristics and Performance

Annual financial characteristics of the cattle operation with each production system are shown in Table 13. Mean cost of purchased hay represented the annual average cost incurred by the cattle operation because of necessary hay purchases. Purchased hay was required in three of the four systems. Bermudagrass/tall fescue systems required more additional hay than the tall fescue systems, and thus incurred higher costs.

Labor was purchased for the cattle operation in each month when the available supply for cattle was insufficient to meet demand. Mean cost of purchased labor was the annual average cost attributed to labor purchases. Fall-calving systems required more labor than did spring-calving systems and thus incurred higher annual costs. Because annual herd size and pasture management did not vary, the amount of annual purchased labor used by each alternative was constant. Cost variability reflected differences in the price of purchased labor each year.

Statistics on annual prices received for calves were summarized for both steer and heifer calves sold. Mean prices indicated the average annual price per hundredweight obtained for steer and heifer calves in the appropriate selling months of each calving system. Cattle price cycles were projected over the 10-year horizon for steers and heifers in varying weight categories. Calf weight and market timing differences of each system were

Table 12. Selected cattle system annual performance statistics for the cattle operation under each forage system with spring- and fall-calving systems.*

	Forage and calving systems**			
Variable	TFSC	TFFC	BFSC	BFFC
Herd size and calf sales				
Cow herd size (head)				
Mean	101	104	126	126
Standard deviation	0	0	0	0
Minumum	101	104	126	126
Maximum	101	104	126	126
Steer calves sold (head)				
Mean	45	46	56	56
Standard deviation	0	0	0	0
Minimum	45	46	56	56
Maximum	45	46	56	56
Heifer calves sold (head)				
Mean	25	25	31	31
Standard deviation	0	0	0	0
Minimum	25	25	31	31
Maximum	25	25	31	31
Cow performance				
Cow weight (pounds)				
Mean	1148.7	1172.6	1087.0	1124.9
Standard deviation	22.4	18.4	48.0	30.9
Minimum	993.9	1067.5	925.6	1020.6
Maximum	1175.7	1189.6	1169.6	1181.7
Milk production (pounds per day)				
Mean	15.53	15.14	15.16	14.12
Standard deviation	0.43	0.41	0.35	0.14
Minimum	14.38	14.08	13.74	13.72
Maximum	16.77	15.89	15.95	14.96
Calf and heifer weights				
Steer calf weaning weight (pounds)				
Mean	544.1	537.8	491.2	470.1
Standard deviation	15.3	13.8	12.6	8.4
Minimum	492.3	492.4	441.1	446.9
Maximum	583.7	579.7	521.4	522.4

Table 12, continued.

Variable	Forage and calving systems**			
	TFSC	TFFC	BFSC	BFFC
Heifer calf weaning weight (pounds)				
Mean	460.6	455.7	418.2	401.0
Standard deviation	12.4	11.1	10.2	6.8
Minimum	418.8	419.0	377.7	382.2
Maximum	492.6	489.3	442.5	443.1
Replacement heifer breeding weight (pounds)				
Mean	645.5	682.5	568.5	602.9
Standard deviation	16.1	11.4	11.0	8.0
Minimum	588.4	644.4	530.0	581.7
Maximum	701.0	724.4	598.4	658.2
Replacement heifer calving weight (pounds)***				
Mean	998.7	1000.0	883.4	926.7
Standard deviation	5.0	0.0	11.2	10.9
Minimum	952.0	1000.0	841.2	902.4
Maximum	1000.0	1000.0	990.6	1000.0

* The statistics presented in this table were based upon annual measurements of each variable for 100 iterations of 10 years. Thus, statistics were based upon a sample size of 1,000 observations.

** The forage and calving systems are: TFSC = tall fescue and spring calving; TFFC = tall fescue and fall calving; BFSC = bermudagrass/tall fescue and spring calving; and BFFC = bermudagrass/tall fescue and fall calving.

*** Replacement heifer weights were constrained at 1,000 pounds, the assumed weight of a brood cow in good condition.

reflected in differences in calf prices received.

On the average, fall-born calves were sold for approximately 3 to 5 dollars more per hundredweight than spring-born calves. Fall-born calves were sold at weaning in June, whereas spring-born calves were weaned and sold in October. The annual average price differences between these months provided a clear marketing advantage for the fall-calving system. Annual price received for calves was also higher in the bermudagrass/tall fescue systems compared to the tall fescue systems. Calves produced in the bermudagrass/tall fescue systems were marketed at a lighter weight than calves in the tall fescue systems, and thus were sold for a higher price.

Mean gross receipts was the annual average dollar value obtained from the sale of farm outputs. Gross receipts were generated by annual steer and heifer calf sales, nonbreeding heifer sales, culled cow and bull sales, and cow-calf pair sales, in addition to any hay sold. Production systems including fall calving generated a greater annual value of sales than those using spring calving. The price advantage associated with marketing fall-born calves was reflected in higher gross receipts. Higher gross receipts were also obtained with the bermudagrass/tall fescue systems relative to the tall fescue systems. Larger sales volumes and higher prices were achieved in these systems, even though selling weights were lower.

Annual operating expenses were the cash expenses incurred by the cattle operation during the course of each year. Pasture, hay, cattle, labor, and operating capital costs accounted for the annual operating expenses. Mean operating expenses indicated the annual average cash outlay for the purchase of items in each of the cost categories.

Table 13. Selected annual financial statistics for the cattle operation under each forage system with spring- and fall-calving systems.*

Variable	Forage and calving systems**			
	TFSC	TFFC	BFSC	BFFC
Costs of purchased hay and labor				
Cost of purchased hay (dollars)				
Mean	0	7	314	179
Standard deviation	0	49	120	148
Minimum	0	0	0	0
Maximum	0	652	562	784
Cost of purchased labor (dollars)				
Mean	1103	1272	1023	1446
Standard deviation	174	201	161	239
Minimum	862	994	799	1035
Maximum	1411	1627	1309	1879
Prices received for calves				
Steer calf price (dollars per cwt.)				
Mean	87.72	90.85	91.37	96.67
Standard deviation	10.48	9.83	11.88	11.37
Minimum	65.30	68.35	65.30	68.90
Maximum	118.05	122.47	127.83	132.42
Heifer calf price (dolloars per cwt.)				
Mean	77.77	82.12	77.91	83.78
Standard deviation	10.48	9.94	10.56	10.65
Minimum	52.46	56.73	52.46	56.73
Maximum	106.89	112.22	106.89	114.02
Receipts and expenses				
Gross receipts (dollars)				
Mean	43480	45784	50323	50554
Standard deviation	5246	4995	6199	5760
Minimum	32679	33658	38085	37602
Maximum	57904	61762	68418	68050
Operating expenses (dollars)				
Mean	19933	20616	24006	24641
Standard deviation	2453	2554	3010	3072
Minimum	16623	17100	19699	20302
Maximum	24472	25584	29677	30884

Table 13, continued.

Variable	Forage and calving systems**			
	TFSC	TFFC	BFSC	BFFC
Fixed expenses (dollars)				
Mean	9101	9311	10733	10811
Standard deviation	2109	2156	2494	2505
Minimum	6318	6428	7472	7472
Maximum	12979	13273	15350	15418
Tax expenses (dollars)				
Mean	722	861	803	753
Standard deviation	755	841	863	848
Minimum	0	0	0	0
Maximum	2555	2796	2741	2665
Net returns				
Net returns above operating expenses (dollars)				
Mean	23547	25168	26317	25913
Standard deviation	5294	5337	6272	6183
Minimum	12741	13101	13785	13126
Maximum	34306	36350	39300	38370
Net returns above operating and fixed expenses (dollars)				
Mean	14438	15857	15544	15100
Standard deviation	6182	6488	7334	7542
Minimum	2998	3668	1925	1779
Maximum	27540	29381	31299	30369
Net returns above operating, fixed, and tax expenses (dollars)				
Mean	13716	14996	14741	14347
Standard deviation	5454	5667	6508	6734
Minimum	2998	3668	1925	1779
Maximum	27540	29381	31299	30369

* The statistics presented in this table were based upon annual measurements of each variable for 100 iterations of 10 years. Thus, statistics were based upon a sample size of 1,000 observations.

** The forage and calving systems are: TFSC = tall fescue and spring calving; TFFC = tall fescue and fall calving; BFSC = bermudagrass/tall fescue and spring calving; and BFFC = bermudagrass/tall fescue and fall calving.

Operating expenses were higher in fall-calving systems compared to spring-calving systems. The added costs were attributed to more purchased hay and labor and to more hay produced in systems with fall-calving herds. Operating expenses were also highest in the bermudagrass/tall fescue systems, for which annual input usage was higher than in tall fescue systems.

Fixed expenses included annual ownership costs for machinery and equipment used in pasture, hay, and cattle production. Because the cattle operation was assumed to be part of a diversified farm where some machinery items are shared among the enterprises, fixed expenses were charged according to the proportion of annual machinery usage in forage and cattle production. Annual machinery use and thus fixed expenses were greater for the bermudagrass/tall fescue systems than for the tall fescue systems because of the larger herd sizes. Fixed expenses were also slightly higher for the fall-calving than the spring-calving systems because of a greater annual usage of hay production equipment.

Income tax expenses were charged each year on returns above the operating and deductible fixed expenses. Mean tax expense for a production system was the annual average tax payment on net income. Tax expenses, therefore, were greater for the higher returning alternatives. Annual variation in tax expense was due to annual receipt and expense variations, as well as tax bracketing.

Annual net returns were computed above each of the expense categories. Summarized return measures were the net return above operating expenses, above operating and fixed expenses, and above operating, fixed, and tax expenses. Means of each category were the annual average net return generated by the cattle operation with each production system.

The BFSC system provided the highest annual average net return above operating expenses ($26,317), followed by the BFFC ($25,913) and TFFC ($25,168) systems. Fall-calving systems generally had a higher average return above operating expenses than spring-calving systems. Higher gross receipts from sales in the fall-calving systems tended to more than offset the higher operating expenses. Likewise, bermudagrass/tall fescue systems provided higher returns above operating expenses than tall fescue systems, with the higher returns offsetting the higher costs. When fixed costs were deducted, the average net return comparisons changed. Fall-calving was still generally more profitable than spring-calving; however, tall fescue systems compared more favorably with the bermudagrass/tall fescue systems. Among the production systems, TFFC provided the highest mean net return above operating and fixed expenses ($15,857), followed by the BFSC alternative ($15,544). The identical ranking of production systems by net returns was obtained when tax expenses were deducted. TFFC and BFSC systems were most profitable ($14,996 and $14,741, respectively), whereas BFFC and TFSC systems were least profitable ($14,347 and $13,716, respectively).

A comparison of the variability of net returns above operating, fixed, and tax expenses was used to measure the relative riskiness of the production systems. Although fall-calving systems were generally more profitable, they also were more risky than spring-calving systems. As measured by the standard deviations, annual returns varied by about $200 more in fall-calving versus spring-calving systems. Likewise, bermudagrass/tall fescue systems had more variable returns than tall fescue systems. Maximum returns were highest in the BFSC ($31,299) and the BFFC ($30,369) systems, while minimum net returns were highest in the TFFC ($3,668) and TFSC ($2,998) systems. The relatively wide variation in net returns (standard deviation and maximum vs. minimum) for all four systems was further evidence of the riskiness of beef-forage systems in general.

Summary and Conclusions

Uncertain forage production and price conditions provide much of the business risk facing Tennessee cattle producers. This study focused on the interaction between biological and economic variables in the production of weaned beef calves utilizing fescue and fescue-bermuda grass forages. Both spring- and fall-calving systems were evaluated. A cattle operation with specified quantities of available land, labor, and machinery was used as the unit of analysis.

A system approach was used to describe the operation of the beef-forage production components. A major objective of the study was to develop a bioeconomic beef forage model suitable for comparing alternative forage grazing and cow management systems used in feeder-calf production in a risky environment. The computer simulation model developed was dynamic, stochastic, and recursive. Six interrelated components were included: climate, forage, cattle, managerial, price and cost, and budgetary units. Forage production data from experimental plots were combined with climate data over a 37-year period to estimate stochastic forage production functions, in both quantity and quality terms. The net energy system (National Research Council, 1984) was used for specifying available and required nutrients for both maintenance and growth of various types and sizes of beef animals in the beef production systems. Operation of the simulation model involved monthly periods during which

accumulated forage and cattle variables were estimated and then evaluated to determine management decisions. Using Monte Carlo techniques to generate random conditions, forage production and cattle weights were simulated over a 10-year planning horizon for 100 iterations. Stochastic cattle prices were also developed by projecting the cattle cycle via harmonic functions.

Several output variables, including annual forage, cattle, and financial performance, were estimated and compared among the production alternatives. Over the simulated periods, average per-acre bermuda/fescue forage yields were about 400 pounds of dry matter higher than for fescue only pastures. Neither of the forage systems exhibited substantial yield and quality fluctuations. Fall-calving herds required more hay from both inventory and purchase than did spring-calving herds. Likewise, bermuda/fescue systems generally required more supplemented hay than fescue only systems. Forage production in any year over the simulated periods was never low enough to necessitate stocking adjustments.

Mean weaning weights over the simulated periods for both steer and heifer calves were nearly 60 pounds greater for the fescue only as compared to the bermuda/fescue pastures. Spring-born calves were generally weaned at heavier weights than fall-born calves. On the average, fall-born calves were sold for approximately 3 to 5 dollars more per hundredweight than spring calves — primarily because of differences in time of marketing. Annual prices received for calves were also higher for bermuda/fescue than for fescue only systems because of differences in weight classes marketed from each systems.

Fall-calving systems were generally more profitable, but they were also more risky (higher net returns variability). Higher production cost for the fall-calving systems were more than offset by the higher calf prices. Bermuda/fescue pasture systems, likewise, generally showed higher but more variable returns than fescue only pasture. Bermuda/fescue with fall-calving alternative resulted in highest return during the periods of high cattle price, and the fescue only system with fall-calving generated the highest return during the lowest cattle price period. The relatively wide variation in net returns (standard deviation and minimum vs. maximum) for all four systems was further evidence of the riskiness of beef-forage systems in general.

A high degree of interrelationship existed among the variables included in the analysis. No one production system was clearly preferable across the range of conditions expected to prevail over time where wide variations in climate, market prices conditions, and risk preferences of decision makers exist. The system approach used here clearly demonstrates the need to evaluate research results from disciplinary studies in a board integrated framework.

Limitations of the Study

The model developed in this study has several limitations with implications for the validity of the results. Caution, therefore, must be exercised in interpreting the results and the conclusions they may suggest.

An important limitation concerns the estimation of forage yield and yield variability during a year. Because of the significant time and expense involved in conducting forage production research, primary data on forage yield and quality were limited. Only yield measurements on each forage species were available. Secondary data on forage quality were employed as estimates of monthly forage quality. Furthermore, the functional forms specified to estimate the forage-climate relationships have restricted ability to describe typical seasonal production peaks and slumps. Tall fescue normally exhibits a decline in production during summer months (Buckner, 1985). This characteristic, however, was not represented adequately by the equation specified for tall fescue yield. Consequently, yields were likely overestimated in some months and underestimated in other months. Other attempts to overcome such problems have used linear yield equations for various seasons of the year (e.g., Riechers, 1986). This approach, however, requires a substantial amount of forage data during each season. A possible alternative approach to estimating forage yield and yield variability is the use of a spline function (Suits et al., 1978) with polynomial segments for different periods of a year.

The narrow range by which annual forage yield was observed to vary suggests that yield variability was underestimated in this study. The limited amount of yield variability resulted in little variation in model results with respect to hay feeding or diversion of hay acreage to grazing, and no necessary adjustments in stocking levels. Severe climatic fluctuations in recent years and the implications for cattle producers (McCampbell, 1988; Williams, 1986) cause speculation that yield variability was underestimated.

Limitations associated with the functional forms of the forage equations, mentioned previously, likely attributed to this result. Inclusion of more alternative species and mixtures would also increase the realism of the model. Limitations are also inherent in the cattle performance component of the model. Animal protein requirements and availabilities were not considered. With the forages

evaluated in this study, protein requirements of the cow-calf pair were assumed to be met when sufficient energy was obtained from grazing. However, during the winter seasons when lower quality hay forages are fed, protein deficiencies are more likely. Some type of protein supplementation may be necessary during these periods. Also, protein considerations become more important for growing animals, such as in the development of replacement stock.

Model refinements would certainly enhance the capability to estimate body composition of cows and growing heifers. Simplistic procedures were developed to describe the energy transfer from forage intake to muscle development and fat. Conversely, little detail was used to describe how fat may be utilized as an energy source when the forage supply is limited.

Dry matter intake of beef cows is extremely variable and difficult to specify. Estimates of forage intake used in this study varied solely by forage quality (percent TDN) and animal weight. More precise estimates, however, could be specified if environmental factors, animal productive stage and available protein were more fully considered (National Research Council, 1984, pg. 31-32). Likewise, selective grazing normally exhibited by cattle was omitted in this analysis because of measurement difficulties. Selective grazing has important implications for the performance of beef animals and pasture composition and growth.

Other measures of performance that could be significant were omitted from the model. For example, while conception, calving, disease problems, and death rates may vary each year with pasture types and breeding and calving periods, data were unavailable to measure these potential differences among the production systems. Further analyses would certainly be enhanced by a more detailed specification of these critical variables.

Climatic conditions and the resulting forage production were used as the sole basis for decision making by cattle producers. In actual practice, however, producers respond to both production and price variations. No feedback mechanisms were specified for how cattlemen would respond to changes in cattle prices. Decisions to sell calves early or postpone marketing in relation to price, as well as climatic fluctuations, would add to the representation of producer behavior.

Implications for Further Research

Simulation modeling is an extremely flexible technique capable of handling the dynamic, stochastic, and recursive characteristics of forage-beef production. The model developed in this study could be modified to examine several other management strategies that would be valuable for making recommendations to Tennessee cattle producers. At this point, however, a more rigorous validation of model capabilities for replicating the characteristics and performance of forage-beef systems is needed.

Several limitations of the model were presented in the previous section. The initial step toward further research involves addressing these shortcomings. Refinements are absolutely necessary in the procedures used to estimate forage yield and yield variability. Additional data on forage yield of alternative species and mixtures would be of great benefit. Likewise, forage quality and composition data are needed. The estimation of yield and quality variations would certainly be enhanced by alterations in the functional relationships among forage production and climatic variables. Measuring cattle performance could be improved by consideration of protein requirements and availabilities. Further refinements in techniques used for measuring intake, such as specification of the influences of environmental factors and selective grazing, deserve attention. Ultimately, a comparison of simulation results to those obtained in actual cattle grazing experiments would offer a means of model validation or would suggest areas in which further refinements in modeling techniques are warranted.

More development of the decision criteria used in the model would be valuable. Testing is needed to examine the sensitivity of model outputs to variations of critical decision parameters, such as stocking levels and hay management. Feedback mechanisms from price variations, in addition to climatic variations, would be more representative of producer behavior. Eventually, alternative decision criteria could be incorporated and evaluated in terms of their utility at the producer level.

Much of the feeder cattle production in Tennessee occurs on small supplemental farm enterprises. Typically, resources utilized in cattle production have few other uses. Further model developments that attempt to describe the role of cattle production within the whole farm framework could enhance the understanding of Tennessee beef production.

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Appendix

Appendix Table 1. Inventory of land resources on the cattle operation.

Soil series	Soil mix of acreage
	percent of acreage
Memphis	33
Grenada	29
Loring	22
Lexington	9
Calloway	4
Henry	3
Total	100

Source: Analysis of 1982 National Resource Inventory Data for Selected Counties in west Tennessee.

Appendix Table 2. Labor supply, crop requirements, and available labor for cattle production in each month on the cattle operation.

Month	Labor supply*	Crop labor requirements**		Labor for cattle
		Cotton	Soybeans	
	hours			
January	333.3	0.0	0.0	333.0
February	333.3	0.0	0.0	333.0
March	333.3	42.9	22.5	267.6
April	333.3	68.2	87.5	177.3
May	333.3	68.2	175.0	89.8
June	333.3	85.4	115.0	132.6
July	333.3	100.1	112.5	120.4
August	333.3	0.0	47.5	285.5
September	333.3	0.0	72.5	260.5
October	333.3	11.0	72.5	249.5
November	333.3	0.0	47.5	285.5
December	333.3	0.0	0.0	333.0
Total	4000.0	375.8	752.5	2867.7

* Labor supply was based upon 50 hours per week of operator labor and 30 hours per week of family labor for 50 weeks per year. Hours are spread evenly between the months.

** Crop labor requirements are based upon 110 acres of cotton and 250 acres of soybeans. Cotton was custom harvested. Estimates were determined using Tennessee budgets (Johnson, 1987a).

Appendix Table 3. Machinery and facility complement of the cattle operation.

Item	Purchase price* (dollars)	Salvage value (dollars)	Economic life (years)
Permanent Fencing (2.6 mi)**	2087.00	0.00	20
Temporary fencing***	356.00	0.00	20
Corral materials****	1027.00	0.00	20
Headgate (manual)	225.00	0.00	10
5 Salt/mineral feeders	330.00	0.00	10
5 Large bale feeders	390.00	0.00	8
Water system*****	774.00	0.00	10
3 Shade shelters******	1602.00	0.00	20
Pickup truck	9070.00	1500.00	7
Gooseneck trailer	3200.00	700.00	8
Tractor (50 HP)	15000.00	4500.00	10
Plow (4-14")	2377.00	400.00	10
Disk (12')	3589.00	600.00	10
Harrow (14')	1365.00	200.00	10
Fertilizer spreader (8')	1542.00	400.00	6
Cultipacker seeder (8'4")	2927.00	500.00	10
Manure spreader (13')*******	3858.00	400.00	10
Rotary mower (10')	3255.00	500.00	8
Mower conditioner (10')	6244.00	1000.00	8
Large round baler	11108.00	2200.00	10
Rake (side delivery)	1904.00	300.00	10
Large bale mover	310.00	50.00	10

* Purchase price of each item at the beginning of the planning horizon (1988).

** Permanent fencing includes barbed wire, steel posts, corner and gate posts, and gates.

*** Temporary fencing includes electric wire, charger, posts, and connectors.

**** Corral materials include lumber, posts, gates, and nails.

***** Water system includes 3 tanks and pipe from well.

****** Shade shelters are permanent structures made of wood with open sides and a covered top. Included are materials needed for construction (e.g., lumber, posts, etc.).

******* The manure spreader was used only in the bermudagrass system to scatter sprigs at establishment.

Appendix Table 4. Sequence and timing of operations and per-acre performance rates for pasture management and hay harvesting with two forage systems, upland soils, west Tennessee, 1988.

	Tall fescue				Bermudagrass/tall fescue			
Operation	Date	Times over	Machine hours	Labor hours	Date	Times over	Machine hours	Labor hours
Pasture management								
Establishment								
Plow	July	1.00	0.59	0.74	March	1.00	0.59	0.74
Disk and harrow	July - August	2.00	0.72	0.90	March - April	2.00	0.72	0.90
Fertilize and lime	August	2.00	0.68	0.86	April	2.00	0.68	0.86
Seed/sprig*	August	1.00	0.25	0.31	April	1.00	0.20	0.25
Herbicide	—	—	—	—	April	1.00	0.34	0.43
Disk**	—	—	—	—	April	1.00	0.18	0.22
Disk***	—	—	—	—	September	1.00	0.18	0.22
Seed	—	—	—	—	September	1.00	0.23	0.29
Total				2.81				3.91
Prorated over 10 years				.28				.39
Annual								
Fertilize	March - September	2.00	0.68	0.86	March - September	2.00	0.68	0.86
Mow	June - August	1.00	0.36	0.45	June - August	1.00	0.36	0.45
Total				1.31				1.31
Hay harvesting****								
Mow and condition	June - September	1.00	0.52	0.65	June - September	1.00	0.52	0.65
Rake	June - September	1.00	0.32	0.40	June - September	1.00	0.32	0.40
Bale	June - September	1.00	0.41	0.51	June - September	1.00	0.41	0.51
Store bales	June - September	—	0.50	0.55	June - September	—	0.50	0.55
Total				2.11				2.11

* The hybrid bermudagrass stand was propagated from sprigs, which were scattered with a manure spreader.

** Light disking to incorporate sprigs and herbicide into soil.

*** Light disking to loosen soil before drilling fescue seed.

**** First and second cutting hay were harvested in June and September, respectively. Performance rates were identical at each cutting.

Appendix Table 5. Per-head labor requirements by month for feeder calf production in spring- and fall-calving herds.*

Month	Spring herd	Fall herd
	hours per head**	
January	1.00	1.10
February	1.25	0.90
March	0.90	0.50
April	0.65	0.65
May	0.85	0.50
June	0.60	1.10
July	0.60	0.75
August	0.60	0.60
September	0.65	0.75
October	1.00	1.00
November	0.65	0.75
December	0.75	0.90
Total	9.50	9.50

* Per-head requirements were for a cow-calf unit made up of 1.0 cows, 0.88 calves, 0.2 weaned heifers, 0.17 replacement heifers, and 0.04 bulls.

** Requirements were developed using 0.50 hours per head as the minimum amount of labor needed each month for herd observation. Labor needed above this minimum was for additional observation and routine management of the beef herd as follows:
Calving — 1.00 hr/hd: 0.25 in month prior to calving, 0.50 in month of calving, 0.25 in month following calving
Breeding — 0.35 hr/hd
Wintering — 0.25 hr/hd
Calf marketing — 0.35 hr/hd
Vaccinations, pregnancy check, and castration — 0.15 hr/hd
Parasite control (summer) — 0.10 hr/hd

Source: Synthesized from Williams (1975) and Taylor (1984).

Appendix Table 6. Estimated expenses per acre for pasture management and hay harvesting under two forage systems, upland soils, west Tennessee, 1988.

		Tall fescue			Bermudagrass/Tall fescue		
Item	Unit	Cost/unit ($)	Quantity	Cost ($)	Cost/unit ($)	Quantity	Cost ($)
Pasture management							
Establishment expenses							
Fescue seed	LBS	1.03	15.00	15.45	1.03	15.00	15.45
Bermuda sprigs	BU	—	—	—	1.06	20.00	21.20
Fertilizer							
N	LBS	0.22	60.00	13.20	0.22	60.00	13.20
P2O5	LBS	0.24	60.00	14.40	0.24	60.00	14.40
K2O	LBS	0.14	60.00	8.40	0.14	60.00	8.40
Lime	TON	13.83	2.00	27.66	13.83	2.00	27.66
Herbicide	LBS	—	—	—	4.00	3.00	12.00
Machinery							
Variable*	AC	13.08	1.00	13.08	17.72	1.00	17.72
Fixed**	AC	28.86	1.00	28.86	39.75	1.00	39.75
Total establishment expenses				121.05			176.38
Prorated over 10 years				12.11			17.64
Annual expenses							
Fertilizer							
N	LBS	0.22	60.00	13.20	0.22	90.00	19.80
P2O5	LBS	0.24	30.00	7.20	0.24	30.00	7.20
K2O	LBS	0.14	30.00	4.20	0.14	30.00	4.20
Machinery							
Variable*	AC	5.26	1.00	5.26	5.26	1.00	5.26
Fixed**	AC	8.99	1.00	8.99	8.99	1.00	8.99
Prorated estab. cost	AC	12.11	1.00	12.11	17.64	1.00	17.64
Total				50.96			63.09
Hay harvesting							
Twine	TON	0.58	1.50	0.87	0.58	1.50	0.87
Machinery							
Variable*	AC	14.89	1.00	14.89	14.89	1.00	14.89
Fixed**	AC	36.62	1.00	36.62	36.62	1.00	36.62
Total				52.38			52.38

* Variable machinery expenses include repairs, fuel, and lubrication.

** Fixed machinery expenses include depreciation, interest, and insurance.

Appendix Table 7. Estimated beef cow-calf expenses per cow, 100-cow unit, west Tennessee, 1988.

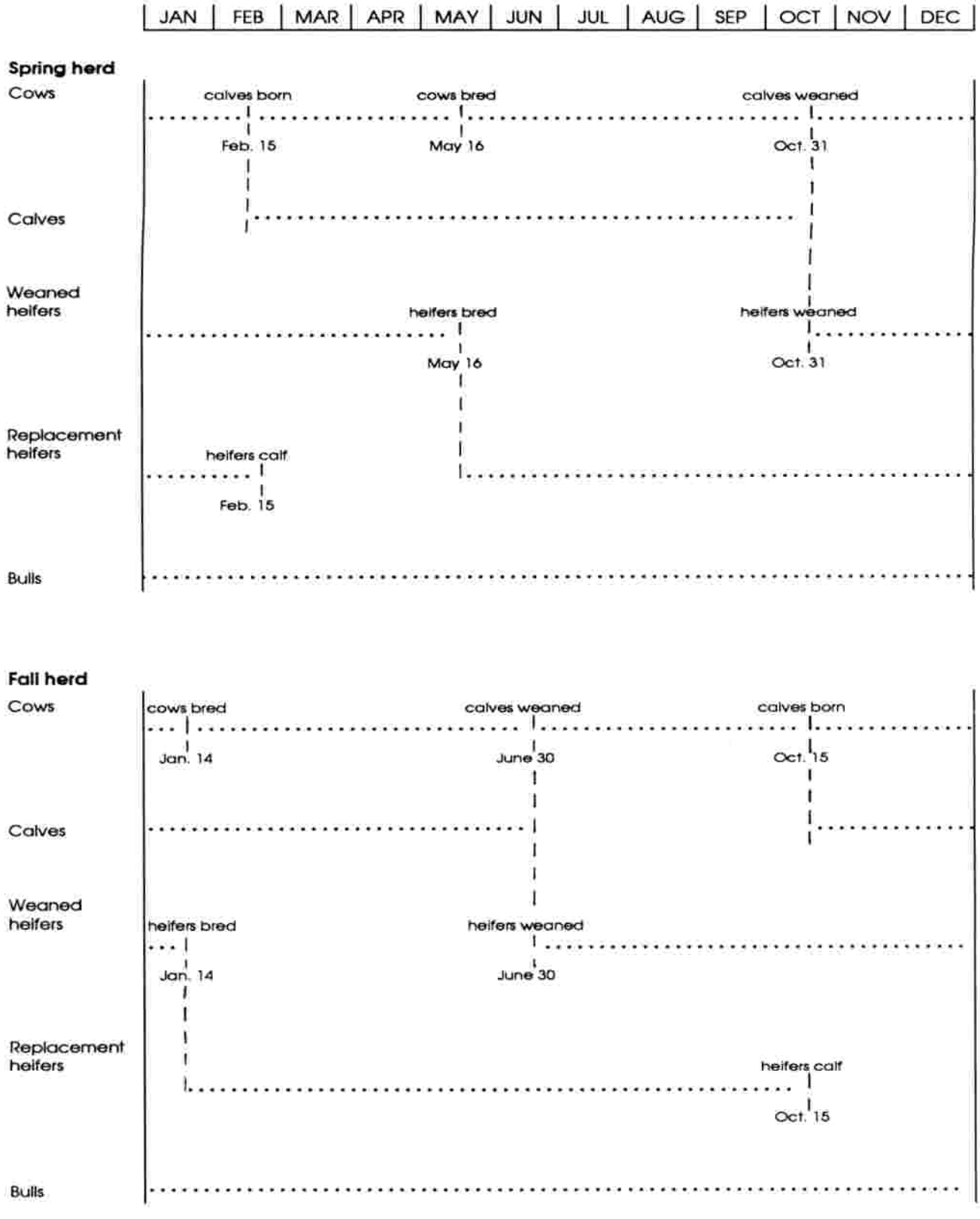
Item	Unit	Unit cost	Quantity	Total cost
Variable expenses				
Feed*				
Pasture	AC	—	—	0.00
Hay	TON	—	—	0.00
Salt and minerals**	COW	4.42	1.00	4.42
Veterinary/medicine***	COW	13.12	1.00	13.12
Marketing****	COW	6.15	1.00	6.15
Herd bulls (800 lbs)	CWT	100.00	0.01	8.00
Machinery	COW	11.44	1.00	11.44
Equipment	COW	1.02	1.00	1.02
			Total variable expenses	44.15
Fixed expenses				
Machinery	COW	24.86	1.00	24.86
Equipment	COW	9.06	1.00	9.06
Livestock	COW	70.98	1.00	70.98
			Total fixed expenses	104.90

* Pasture and hay prices and quantities vary by forage and calving systems and, thus, are not included in this budget.

** Assumes 1 ounce per head per day of a salt-dicalcium phosphate mineral mixture at a cost of $0.01 per ounce.

*** Costs consist of four-way Clostridia (Blackleg, etc.) vaccination, five-way Leptospirosis vaccination, vaccination of replacement heifers for Bangs, Pregnancy check, Grub and Lice control, Face Fly control, and Internal Parasite control.

**** Auction charge of $7.50 per head sold.



• • • Indicates portion of year in which each class of cattle is retained in the operation.

Appendix Figure 1. Timing of production for spring- and fall-calving herds.

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