

AN ECONOMIC COMPARISON OF CONTROL
METHODS OF WYOMING BIG SAGEBRUSH IN
SOUTHWESTERN MONTANA

by

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APPROVAL

of a thesis submitted by

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

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ABSTRACT

Big sagebrush (Artemisia tridentata Nutt.) is a very inefficient user of water and competes strenuously for moisture with more desirable forage plants such as grasses, forbs, and other shrubs. Several control methods have been developed in hopes of increasing range productivity for domestic livestock grazing. Spraying with 2,4-D, burning, plowing and seeding, and rotocutting are the primary means of controlling sagebrush.

The objective of this thesis was to conduct an economic comparison among these four Wyoming big sagebrush control methods and determine optimal retreatment intervals. Production of perennial grasses was measured on experimental plots in southwestern Montana 12 years during the period 1963-1986. The data were used to estimate the treatment response function. Sagebrush control is a stochastic dynamic problem and as such the problem was formulated within a stochastic dynamic programming framework. The economic criterion was the expected present value of additional net returns from sagebrush treatment. Decision alternatives included in the DP model were keeping or retreating the sagebrush. The state variables were years since treatment and expected value of forage yield per AUM which was defined as a function of calf price. Based upon a statistically estimated second-order autoregressive difference equation, the calf price transition probability distribution was developed.

Given the data available to this study, Wyoming big sagebrush treatment methods of spraying and burning were economically feasible, with spraying the most profitable. Rotocutting was only marginally feasible, and plowing and seeding was not feasible. From the study results it was also concluded that in addition to treatment method, treatment cost and the quantity of sagebrush killed, the expected present value of additional net return and optimal retreatment interval also depend upon previous calf price trend.

CHAPTER 1

INTRODUCTION

Statement of the Problem

Big sagebrush (Artemisia tridentata Nutt.) grows on nearly 60 million hectares in the Western United States (Beetle, 1960). Beetle described big sagebrush as an erect, gray-green shrub. It is characterized by an aromatic smell and three toothed leaves. Big sagebrush may appear either dwarfed, shrubby or treelike. Competing with other plant species for water, nutrients, and space, it is not a desirable species for domestic livestock grazing. Rittenhouse and Sneva (1976) reported that perennial grass production declined 3.3 to 5.7 percent for every 1 percent increase in brush cover. If economically feasible, domestic livestock producers prefer the replacement of sagebrush with species which would enhance domestic livestock grazing. Therefore, sagebrush management strategies have been the subject of considerable research and application. However, only a few studies deal with economic considerations of these strategies. It is important to transform the biological response to sagebrush treatment into monetary value for a comparison of economic efficiency among available treatment choices for domestic livestock grazing.

Objectives of the Project

The purpose of this study is to conduct an economic comparison among four Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis, Beetle and Young) treatment methods: spraying with 2,4-D, burning, plowing and seeding, and rotocutting. Comparisons are based upon expected present value of additional net returns of perennial grass production realized after application of the four treatments.

While this study focuses on domestic livestock grazing, the treatment of sagebrush may impact soil erosion and contamination, water retention, and wildlife habitat. Although these are important considerations in the sagebrush management decision, they are beyond the scope of this study.

This study will address the following question: Are these sagebrush treatments economically feasible? If so, how often should they be imposed? What level of sagebrush canopy cover warrants imposing the treatment?

Outline of the Thesis

The next chapter reviews the literature on previous comparisons of sagebrush treatment methods. Chapter 3 presents the methodology for choosing a sagebrush management strategy. The fourth chapter contains empirical results and discussion. Concluding remarks are the topic of Chapter 5.

CHAPTER 2

LITERATURE REVIEW

Sagebrush management strategies have been the focus of many publications, with most concentrating on the biology of sagebrush treatment. Previous economic analyses computed the present value of the net benefits from a single treatment of sagebrush over a prespecified period.

Among the first to demonstrate the effectiveness of 2,4-D for destroying big sagebrush were Elwell and Cox (1950), Cornelius and Graham (1951), and Hull and Vaughn (1951). Working independently, Hull et al. (1952) and Bohmont (1954) demonstrated the usefulness of 2,4-D in Wyoming, and Hyder (1953) demonstrated its usefulness in eastern Oregon. Gradually, the brush control program with 2,4-D became widespread. The reported annual increase in forage yield after the treatment varied from as low as 85 percent in a three-year observation (Cook, 1966) to as high as 295 percent in a five-year observation (Alley and Bohmont, 1958). Johnson (1969) reported effective treatment life of 14-17 years on areas not grazed by livestock.

Burning is not a new tool for manipulation of sagebrush-bunchgrass range. Fire was a commonly used technique 50 years ago. After a long-term ecological study with two burns conducted in Idaho in 1936 and 1937, the usefulness of burning as a

sagebrush management strategy was gradually revealed (Britton and Ralphs, 1978). Because of its lower cost, interest in burning has increased in the past 20 years. From data presented by Pechanec et al. (1954) it was concluded that within four years after burning, forage production increased 90 percent; after 15 years it was still 33 percent greater than on an unburned sagebrush range. Studies by Mueggler and Blaisdell (1958) show a 61 percent increase of forage production three years following burning as compared to an untreated range. The effective life of burning reported by Pechanec et al. (1954) lasted for at least 15 years. Whiteworth (1963) claimed 12 years of increased capacity following burning.

Plowing and seeding, and rotocutting are two mechanical treatment methods. A study by Kearl and Brannan (1967) showed an average increase following treatment of 133 and 369 percent for disk plowing and seeding, and rotocutting, respectively. On the other hand, it was thought that costs for these treatment methods were considerably higher and results less dependable than burning and spraying, so "mechanical methods are not considered to be a viable alternative" (USFS, 1973, p. 54).

Assuming that the response to the treatment was constant over an prespecified effective treatment life, Kearl and Brannan (1967) conducted an economic comparison among several sagebrush treatment methods including rotary beating, raiiling, disk plowing and seeding, scraping with patrol or grader, and spraying by computing the present value of net return from a single treatment. From the results of their study it was concluded that patrol and disk plowing followed by

seeding were the most productive methods. Spraying was desirable when terrain and topography prohibited use of the patrol or disk plowing followed by seeding.

A similar study by Nielsen and Hinckley (1975) calculated the internal rate of return for spraying, burning, plowing and seeding, rotobating, and chaining. It was claimed that burning, spraying, and chaining were economically feasible; but plowing and seeding, and rotobating were not economically feasible. The highest internal rate of return was obtained with burning. The shortcomings of the study were similar to those of Kearl and Brannan's (1967) in that the planning period was prespecified and only a single treatment was considered. As the authors pointed out, "Although this method is a relatively easy way to calculate the internal rate of return, it is not as accurate as one may desire" (Nielsen and Hinckley, 1975, p. 13).

Wambolt and Payne (1986) used data from a common site over the 1963 to 1981 time period to compare four sagebrush treatment methods--burning, spraying with 2,4-D, plowing and seeding, and rotocutting. The criterion used was sagebrush canopy cover and forage production level. The conclusion reached was that "if control of Wyoming big sagebrush to increase understory production is the management objective, then spraying with 2,4-D and burning are more effective than rotocutting or plowing and seeding" (p. 319).

CHAPTER 3

METHODOLOGY

For the purpose of this study, the objective of the decision maker is to maximize the present value of the additional net returns from livestock grazing. The decision maker will then choose among sagebrush treatment methods and levels. Specifically, the decision maker will maximize

$$PV = \sum_{t=1}^{\infty} (R_t - C_t) / (1 + r)^t \quad (3.01)$$

where

PV = present value of additional net returns

R_t = additional returns in year t , which is the product of the unit value of the forage and the additional yield due to sagebrush treatment

C_t = treatment costs in year t

r = discount rate

To maximize equation (3.01), the decision maker chooses the method of treatment, how much to treat, and how often to treat. In making these decisions, the decision maker is concerned with the forage production response to the treatment, the value of the forage, and the costs of the treatment.

In this study four treatment methods were analyzed: spraying, burning, plowing and seeding, and rotocutting. The treatments were analyzed under one intensity level, i.e., various amounts of spray or

fuel quantities were not considered. Data to analyze different intensities were not available. Thus, the implicit assumption is that the experiment from which the data were obtained was designed such that the treatment intensities were optimal.

The forage production response to sagebrush treatment was estimated using data obtained in Montana.

Study Site And Field Data

The study site from which forage production response to Wyoming big sagebrush treatments was measured is located approximately 27 km west of Dillon in southwestern Montana. The big sagebrush--bluebunch wheatgrass habitat type, which receives about 310 mm of precipitation annually--is typical of much rangeland in the region. A more detailed description of the site is provided by Wambolt and Payne (1986).

Production responses from three treatments (spraying with 2,4-D, plowing and seeding, and rotocutting) applied in 1963 were sampled in 1964, 1965, 1966, 1967, 1970, 1976, 1977, 1978, 1981, 1985 and 1986, totaling 11 years. Because burning was applied one year later (1964) than the other treatments, its production response began in 1965. Each treatment was replicated four times resulting in 44 observations (4x11) for spraying, plowing and seeding, and rotocutting, and 40 observations (4x10) for burning. The four replications of the study control (no brush treatment) were averaged to serve as the proxy variable for environmental conditions. Total perennial grass production was used to represent desirable forage as

no livestock browse was encountered and utilizable forbs were scarce (Wambolt and Payne, 1986).

Formulation of Forage Response
Function to Sagebrush Treatment

The value of the treatment depends upon the forage response subsequent to the treatment. In formulating a forage response model, two considerations are important, the appropriate algebraic form and the relevant variables.

The choice of a response function depends upon the biology of the response process. While such knowledge is limited, intuitively it seems that desirable forage would increase after the treatment application, reach a peak, eventually decline as the sagebrush reinvades, and after an extended period of time approach an equilibrium which may or may not be the same as the equilibrium prior to treatment. Such a response function is shown in Figure 1.

The choice of variables should also depend upon the underlying biology of the response process. It is hypothesized that the treatment type and the time period since treatment application influence forage production. Since sagebrush competes with other forage for space, water, and nutrients, the quantity of forage produced may be influenced by the quantity of killed sagebrush. Environmental conditions also may be important considerations in determining the forage response level. Little environmental data were available (precipitation, temperature, etc.), so the average level of forage response on the control was chosen as a proxy for the

environmental influences. Based upon the considerations mentioned above, the following response function was chosen:

$$Y(t) = \alpha k \beta t^\gamma e^{\delta t} + \theta + u_t \quad (3.02)$$

where

$Y(t)$ = level of forage production, defined as the ratio of forage production with treatment to forage production without treatment at time t (years since treatment was applied)

k = quantity of killed sagebrush, defined as sagebrush canopy cover before treatment was applied ($t=0$) minus sagebrush canopy cover after treatment occurs ($t=1$)

e = Euler's number (2.71828.....)

θ = long-term equilibrium level of forage produced by the treatment relative to the control since $\lim_{t \rightarrow \infty} Y(t) = \theta$

u_t = random disturbance term, assumed to be normally distributed with mean zero

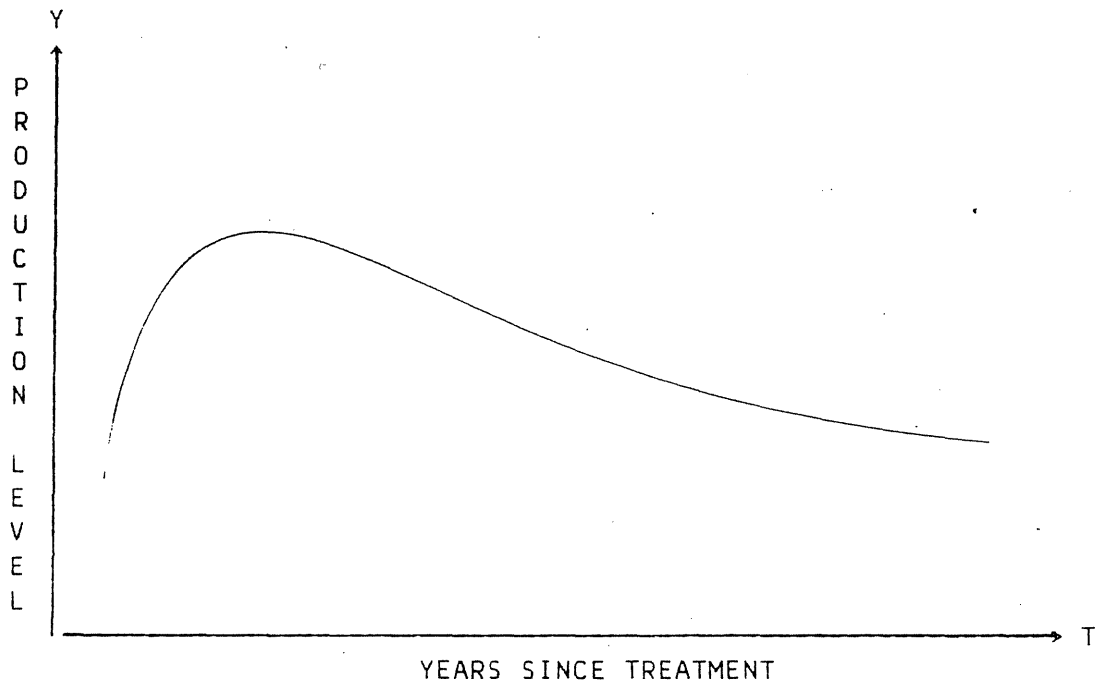


Figure 1. Response function shape.

α , β , γ , δ , and θ are parameters to be estimated from the data. If $\alpha > 0$, $\beta > 0$, $\gamma > 0$, $\delta < 0$ and $\theta > 0$, the function has the desired form (for the derivation of the parameter signs, see Appendix B). That the environmental influences were incorporated by expressing $Y(t)$ as a forage response ratio of the treatment to the control solves the problem of unavailability of environmental data and avoids the complexity of estimation even if such data were available.

Development of DP Model

The optimal policy for sagebrush treatment involves choosing a sequence of decisions on whether and/or when to treat sagebrush, such that the expected present value of additional net returns is maximized. A decision specifies one of the possible alternatives, given expected physical and economic conditions at a particular point in time. A stochastic dynamic problem such as this can be efficiently handled by dynamic programming.

Dynamic programming is a useful mathematical optimization technique to solve multistage decision problems. The pioneering work in dynamic programming was done by Richard Bellman in 1957. Further development and applications have flourished since that time. Since dynamic programming is a general type of approach to problem solving, and the particular equations used must be developed to fit each individual situation, a discussion of the development of the DP model for the sagebrush management problem follows.

Stages

In dynamic programming, the problem is segmented into a number of stages, with a policy decision being made at each stage. The specification of stage and the total number of stages to be considered depend upon the particular problem being studied. For the sagebrush management problem, the decision of whether to retreat is made annually. Therefore, the stage is a time interval and its length is one year. Also, the number of stages chosen should be sufficiently long so that the decision rule and terminal value will be stable and not be affected by the number of stages. Thus a 100-year planning horizon is assumed, with a decision concerning keeping or retreating sagebrush made annually in the late summer. Accordingly, there are 100 stages, each one year in length.

State Variables

The condition or state of the problem under analysis at a particular stage is defined by the magnitude of the state variables. The state variables in the optimization problem at hand must describe both the physical (additional yield potential) and economic conditions that will be encountered at a given stage. Years since treatment, which affects the additional forage yield, and value of forage yield are two such variables describing the physical and economic conditions.

Years since treatment. Years since treatment, t , is a deterministic state variable which denotes the number of years since the treatment was imposed. Choosing the range of t largely depends

upon the effective life of the treatment. Since the locus of the forage production response to treatment was fairly flat after about 20 years (see Figure 4), the t range was assumed from 1 to 30.

Value of forage yield per animal-unit-month. An animal-unit-month (AUM) is the amount of forage required to maintain a 1000 pound cow for one month. The value of forage yield per AUM is a stochastic state variable in the model since the future value is not known with certainty. The calculated value depends upon the technique used. For example, one could take residual ranch income after payment of all costs other than forage and compute the average value per AUM. Another way of handling the problem would be to use market value, usually expressed as a monthly lease rate.

Each analysis of a sagebrush treatment project may have some unique characteristics that influence the appropriate AUM value. In this study, the monthly lease rate was not chosen as the basis for calculating the value of forage yield per AUM upon the following considerations:

1. In Montana, most domestic livestock producers are ranch owners. Leasing of private land for grazing is not a dominant feature. Leasing of public land for grazing is prevalent, but the lease rate is not competitively determined.

2. Since the length of ranch lease is usually more than one year, the lease rate is somewhat vague and does not reflect annual changes in product price.

Residual income was used to compute the expected value of forage per AUM :

$$E(VF) = (E(CP) \times EW - AC) / LGS \quad (3.03)$$

where

$E(VF)$ = expected value of forage per AUM

$E(CP)$ = expected calf price per 100 lbs.

EW = equivalent weight of a calf, which was 4.62 hundred lbs. (for details, see Appendix C)

AC = average costs to raise a calf, which was \$262.41 (for details, see Appendix C)

LGS = length of grazing season, which was 9 months

Note that if imposing sagebrush treatment was viewed as an investment by livestock producers, then the definition of expected value of forage yield in equation (3.03) would make calf price an important determinant in the optimal investment decision process. The results of previous empirical studies generally seem to indicate that livestock price has significant influence on producer's investment. The studies by Freebairn and Rausser (1975), and Martin and Haack (1977) claimed that cattle price is a significant determinant of investment in breeding herd inventory. Rucker et al. (1984) also showed a positive correlation between cattle price and inventory size. Furthermore, the authors pointed out, "Using pasture more intensively to increase production during periods of high prices and letting them recover during periods of low prices through less intensive grazing could be quite rational behavior of ranchers in semiarid regions such as Montana" (p. 132). If a cattle cycle does exist and ranchers are likely to expect future prices to continue to follow a cyclical pattern, then, to expand the operations in response to an upward price trend, they may improve the productivity of the land by investment.

"Various sagebrush control methods are important ways to increase range productivity" (Kearl and Brannan, 1967, p. 9).

Transition Probabilities

As defined earlier, the stochastic state variable--expected value of forage per AUM--is a function of calf price. Calf price is a continuous random variable for which transition probabilities must be calculated.

Calf price equation. The equation was estimated using observations over 13 years (1974-1986) on calf price per 100 pounds in Montana (Montana Agriculture Statistics, 1983-1986). Calf price was expressed in 1986 dollars after deflating by the Consumer Price Index (CPI). The best fit equation was a second-order autoregressive stochastic difference equation. Equation (3.04) gives the estimated coefficients with t-values in parentheses.

$$CP_t = 45.8162 + 1.0841CP_{t-1} - .6388CP_{t-2} + e_t \quad (3.04)$$

(2.394) (3.996) (-2.328)

where

CP_t = calf price in year t

CP_{t-1} = calf price in year t-1

CP_{t-2} = calf price in year t-2

e_t = random disturbance term

The standard deviation of the estimate, adjusted R^2 , and the first-order autocorrelation are 14.3640, .59, and .06, respectively. The hypothesis that the residual is normally distributed was not rejected (see Appendix D).

The estimated calf price difference equation has a conjugate complex root which implies a convergent time path with a repeating cycle every 8.43 years. The cyclical behavior of livestock prices has prevailed for a century. While a few economists (McCulloch, 1975, 1977; Savin, 1977; and Anderson, 1977) have questioned the existence of the cycle, the economics literature of the last decades contains numerous distinct and reasonably well-defined explanations of the price cycle phenomena. In his classical paper "The Cobweb Theorem," Ezekiel (1938) showed that the cyclical nature stems from the response lags between the deviations in past prices and in current outputs. Nerlove (1958) introduced the concept of adaptive expectations to the modeling of agricultural markets. A study by Long and Plosser (1983) demonstrated that the consumption-production plans chosen by maximizing individuals may be an explanation for price fluctuations. From the debates mentioned above, it was inferred that the remaining issue is which theorem may explain the price cycle better, rather than whether this cycle does exist. The debate is beyond the scope of this study.

Transition probabilities. The required conditional probability for calf price is specified below:

$$CP_{ji} = PR(CP_t = i \mid CP_{t-1} \text{ } CP_{t-2} = j) \quad (3.05)$$

where

CP_{ji} = the probability of going to the ith calf price state in year t, given the jth previous calf price state in year t-1 and t-2

The calf price range was from \$60 to \$135, which is centered at \$97.5. Figure 2 shows the calf price midpoints and intervals used in the model.

Since the hypothesis that the residual is normally distributed was not rejected, the calf price transition probabilities were computed using the standardized normal variate below:

$$Z = (CP_m - \mu) / \hat{\sigma} \quad (3.06)$$

where

Z = the standardized normal variate

CP_m = calf price midpoints

μ = the estimated mean

$\hat{\sigma}$ = the estimated standard deviation

The price transition probabilities are presented in Table 1.

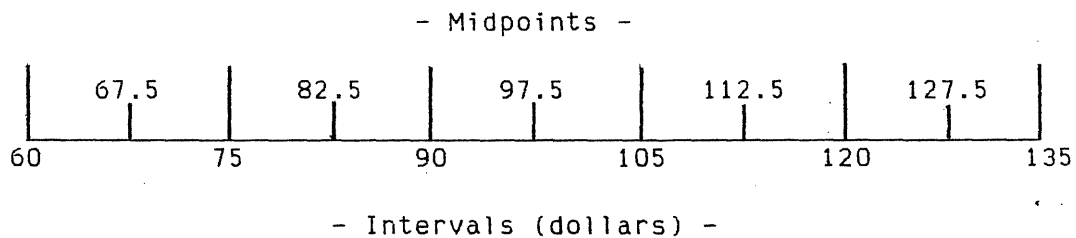


Figure 2. Calf price intervals and midpoints.

Decision Alternatives

A policy decision refers to a plan to make a decision based on a predetermined policy under each possible condition. The decision has to be made from a set of available alternatives at each stage. Decision alternatives considered in this model are:

0) Retreat the sagebrush.

1) Keep the sagebrush.

Note that years since treatment is a deterministic state variable; i.e., once a decision is made at a particular stage, the quantity of additional forage yield at the next stage is known with certainty given a decision. However, value of forage is a stochastic state variable, and the decision made at a particular stage has no effect on the value of forage state at the next stage. Value of forage state transition is a function of the previous calf prices.

Table 1. Probability distribution of calf price at year t , given calf prices at year $t-1$ and year $t-2$.

Previous Calf Price Condition		Calf Price Midpoints CP_t				
CP_{t-1}	CP_{t-2}	67.5	82.5	97.5	112.5	127.5
67.5	67.5	.4761	.3604	.1423	.0201	.0011
67.5	82.5	.7291	.2214	.0459	.0036	.0000
67.5	97.5	.8980	.0918	.0102	.0000	.0000
67.5	112.5	.9738	.0248	.0014	.0000	.0000
67.5	127.5	.9955	.0045	.0000	.0000	.0000
82.5	67.5	.1170	.3240	.3728	.1579	.0283
82.5	82.5	.2981	.4004	.2421	.0549	.0045
82.5	97.5	.5557	.3273	.1041	.0129	.0000
82.5	112.5	.7910	.1768	.0303	.0019	.0000
82.5	127.5	.9306	.0635	.0059	.0000	.0000
97.5	67.5	.0099	.0904	.3049	.3858	.2090
97.5	82.5	.0485	.2224	.3955	.2628	.0708
97.5	97.5	.1611	.3588	.3444	.1195	.0162
97.5	112.5	.3745	.3897	.1966	.0381	.0011
97.5	127.5	.6331	.2846	.0748	.0075	.0000
112.5	67.5	.0000	.0080	.0773	.2892	.6255
112.5	82.5	.0026	.0375	.2019	.3911	.3669
112.5	97.5	.0170	.1231	.3479	.3558	.1562
112.5	112.5	.0721	.2688	.3948	.2178	.0465
112.5	127.5	.2148	.3878	.3006	.0872	.0096
127.5	67.5	.0000	.0000	.0062	.0659	.9279
127.5	82.5	.0000	.0020	.0316	.1812	.7852
127.5	97.5	.0000	.0136	.1074	.3312	.5478
127.5	112.5	.0048	.0570	.2503	.3933	.2946
127.5	127.5	.0274	.1620	.3781	.3194	.1131

Expected Additional Yield

Expected additional yield was defined as the quantity of forage with treatment (kg/ha) minus that without treatment which was set equal to the average quantity of forage produced on the control. In addition, its value should be transformed into AUMs in order to be consistent with the measurement of expected forage value.

Formulation of the expected additional forage yield equation is as follows:

Recall the treatment response function

$$Y(t) = Y_T(t)/Y_{NT}(t) = \alpha k^{\beta} t^{\gamma} e^{\delta t} + \theta \quad (3.07)$$

where

$Y_T(t)$ = forage production level with treatment in the tth year

$Y_{NT}(t)$ = forage production level on the control in the tth year

so

$$Y_T(t) = Y_{NT}(t) \times (\alpha k^{\beta} t^{\gamma} e^{\delta t} + \theta) \quad (3.08)$$

thus

$$Y_T(t) - Y_{NT}(t) = Y_{NT}(t) \times [\alpha k^{\beta} t^{\gamma} e^{\delta t} + (\theta - 1)] \quad (3.09)$$

which is the additional yield.

While there is some difference of opinion on the forage required per AUM, the Forest Service recommendation for the region of the study site of 353kg (USFS, 1983) with a 50% proper use rate was chosen. Also, Y_{NT} was set equal to average level from 1964-1986 on the control, 180.21kg. Therefore, the expected additional forage yield in AUM terms is:

$$\begin{aligned}
 EAY &= [Y_T(t) - Y_{NT}(t)] / (2 \times 353) \\
 &= 180.21 \times [\alpha k^{\beta} t^{\gamma} e^{\delta t} + (\theta - 1)] / (2 \times 353) \\
 &= .2552549 \times [\alpha^{\beta} t^{\gamma} e^{\delta t} + (\theta - 1)] \quad (3.10)
 \end{aligned}$$

Treatment Costs

Treatment cost is an important consideration in choosing the most desirable method of treatment and the optimal retreatment period. The cost of the treatment varies depending upon individual situations. Nielsen and Hinckley's (1975) treatment costs were adjusted to 1986 (Table 2).

Table 2. Summary of treatment costs.

Treatment Method	Treatment Costs	
	Nielsen and Hinckley's (1975) Estimate (\$/ac)	Adjusted to 1986 ^a (\$/ha)
Spraying	5.82	21.37
Rotocutting	7.37	37.19
Burning	4.00	20.18
Plowing and Seeding	21.00	105.97

^aAdjusted for inflation from 1975 to 1986 by CPI (Economic Report of the President, 1987). CPI is 161.2 and 328.4 for 1975 and 1986, respectively, implying an inflation adjustment factor of 2.0372. Transforming from acres to hectares as well as inflation results in a total adjustment factor of 5.046.

The Discount Rate

The additional information necessary to compute the present value of the benefits from the treatments is the discount rate, λ , which was defined as $1/(1 + r)$, where r is the real interest rate (5%).

Recursive Equation

A recursive equation identifies the optimal policy for stage n , given the optimal policy for stage $(n-1)$. It must possess the following three properties. First, a decision is to be made at any stage n . Second, a decision, together with the state of the process at stage n , determines the state of the process at the next stage. Third, for any stage n , the state and the decision determine expected returns for that stage.

Bellman's principle of optimality provides the basis for the formulation of a recursive equation and for the solution technique. This principle states that given the current state, an optimal policy decision for the remaining stages is independent of the policy decisions adopted in the previous stages. An optimal policy is defined as the sequence of decisions that optimizes the objective function.

The objective of the sagebrush treatment problem is to maximize present value of additional net returns from forage production. Application of the principle of optimality gives the following recursive relationship:

$$PV_n(t, PC_j) = \max \left[\begin{array}{l} K \sum_{i=1}^5 PR_{ij} \times [\pi(t, EVF_i) + \\ \lambda PV_{n-1}(t+1, PC_j)] \\ R \{ \sum_{i=1}^5 PR_{ij} \times [\pi(1, EVF_i) + \\ \lambda PV_{n-1}(1, PC_j)] \} - TC \end{array} \right] \quad (3.11)$$

where

- $PV_n(t, PC_j)$ = present value of additional net return at stage n , given previous calf price condition PC_j
- n = stage, 1, ..., 100
- t = years since treatment, $t = 1, \dots, 30$
- PC_j = previous calf price condition, there are 25 combinations of such condition, so $j = 1, \dots, 25$ as presented in Table 1
- K = keep the sagebrush
- R = retreat the sagebrush
- PR_{ij} = probability of moving from the j th previous calf price state to the i th calf price state as presented in Table 1
- $\pi(t, E(VF_i))$ = immediate return with the i th calf price midpoint and t years since treatment, which is the product of $E(VF_i)$ and expected additional yield as defined in equation (3.10)
- $E(VF_i)$ = the i th expected value of forage per AUM as defined in equation (3.03)
- λ = discount rate
- $PC_{\hat{j}}$ = previous calf price condition at stage $n-1$ where
- | | |
|-------------------------------|-------------------------------|
| 1 $\leq j \leq 5$, | $\hat{j} = 1, 6, 11, 16, 21$ |
| 6 $\leq j \leq 10$, | $\hat{j} = 2, 7, 12, 17, 22$ |
| if 11 $\leq j \leq 15$, then | $\hat{j} = 3, 8, 13, 18, 23$ |
| 16 $\leq j \leq 20$, | $\hat{j} = 4, 9, 14, 19, 24$ |
| 21 $\leq j \leq 25$, | $\hat{j} = 5, 10, 15, 20, 25$ |
- TC = treatment cost as presented in Table 2

At each state, an optimal policy decision which yields a maximum present value between the two alternatives was chosen. By using this recursive equation, the solution procedure moves backwards stage by stage, finding an optimal policy for each state at every stage.

Terminal Value

The solution procedure, which begins by solving for PV_1 , requires a value for PV_0 . Here PV_0 was set equal to zero.

CHAPTER 4

RESULTS

Statistical Estimates of the Response Function

The response function for each treatment method was estimated using the same functional form with and without the restricting $\beta=0$ with SAS/ETS SYSNLIN regression software. The estimation method used was Marquardt-Levenberg. The starting values for α , β , γ , δ and θ were 2.5, 1.0, .9, -.3 and 1.0 in the case of spraying, burning, and rotocutting; and 2.7, .1, 13.5, -4.5 and 1.0 in the case of plowing and seeding, respectively.

The results of estimation are presented in Table 3. Graphs of the production responses for each treatment are presented in Figures 3, 4, and 5.

When the functions were estimated without the restriction $\beta=0$ for rotocutting as well as burning, all the parameter signs were as hypothesized, and from the t values associated with the estimated parameters it was inferred that all the variables had a significant influence. The exception was the parameter α in the rotocutting equation where the t value was .76. The R^2 are .5548 and .6731 for rotocutting and burning, respectively. It is not surprising that the influence of the quantity of killed sagebrush, k, is not significantly different from zero for spraying since the variance among k values is

small for the treatment. The k ranged from .08 to .21 and from .11 to .17 for burning and rotocutting, respectively, but was only from .12 to .17 for spraying.

Table 3. Response function statistics (1).^a

Treatment	α	β	γ	δ	θ	SSE	R^2
Spraying ^b	3.19503 (.98)	-.09262 (-.18)	.60218 (1.69)	-.22325 (-2.03)	.64334 (1.15)	46.97062	.6643
Spraying ^c	3.80688 (5.48)		.61121 (1.73)	-.22648 (-2.06)	.65794 (1.21)	47.01323	.6640
Rotocut- ting ^b	22.47123 (.76)	1.31507 (1.88)	1.35806 (1.92)	-.45720 (-1.98)	.90482 (4.30)	25.81935	.5548
Rotocut- ting ^c	1.64720 (3.26)		1.41106 (1.81)	-.44491 (-1.84)	.89303 (3.80)	29.05609	.4990
Burning ^b	3.96645 (2.66)	.37028 (1.75)	.77263 (2.09)	-.18009 (-2.19)	.65967 (1.14)	12.37374	.6731
Burning ^c	1.97634 (2.55)		.74013 (1.84)	-.17257 (-1.91)	.60645 (.89)	13.92577	.6321
Plowing and Seeding ^b	2.65600 (1.10)	-.00386 (-.01)	13.59783 (3.38)	-4.79980 (-3.34)	1.05726 (5.28)	49.39890	.6482
Plowing and Seeding ^c	2.67712 (1.72)		13.61179 (3.43)	-4.80470 (-3.39)	1.05744 (5.35)	49.39919	.6482

^aThe numbers in the parentheses are the t values.

^bFunction was estimated without restriction $\beta=0$.

^cFunction was estimated with restriction $\beta=0$.

In the case of the regressions with the restriction $\beta=0$, all the parameter signs were as hypothesized, and from the respective t values

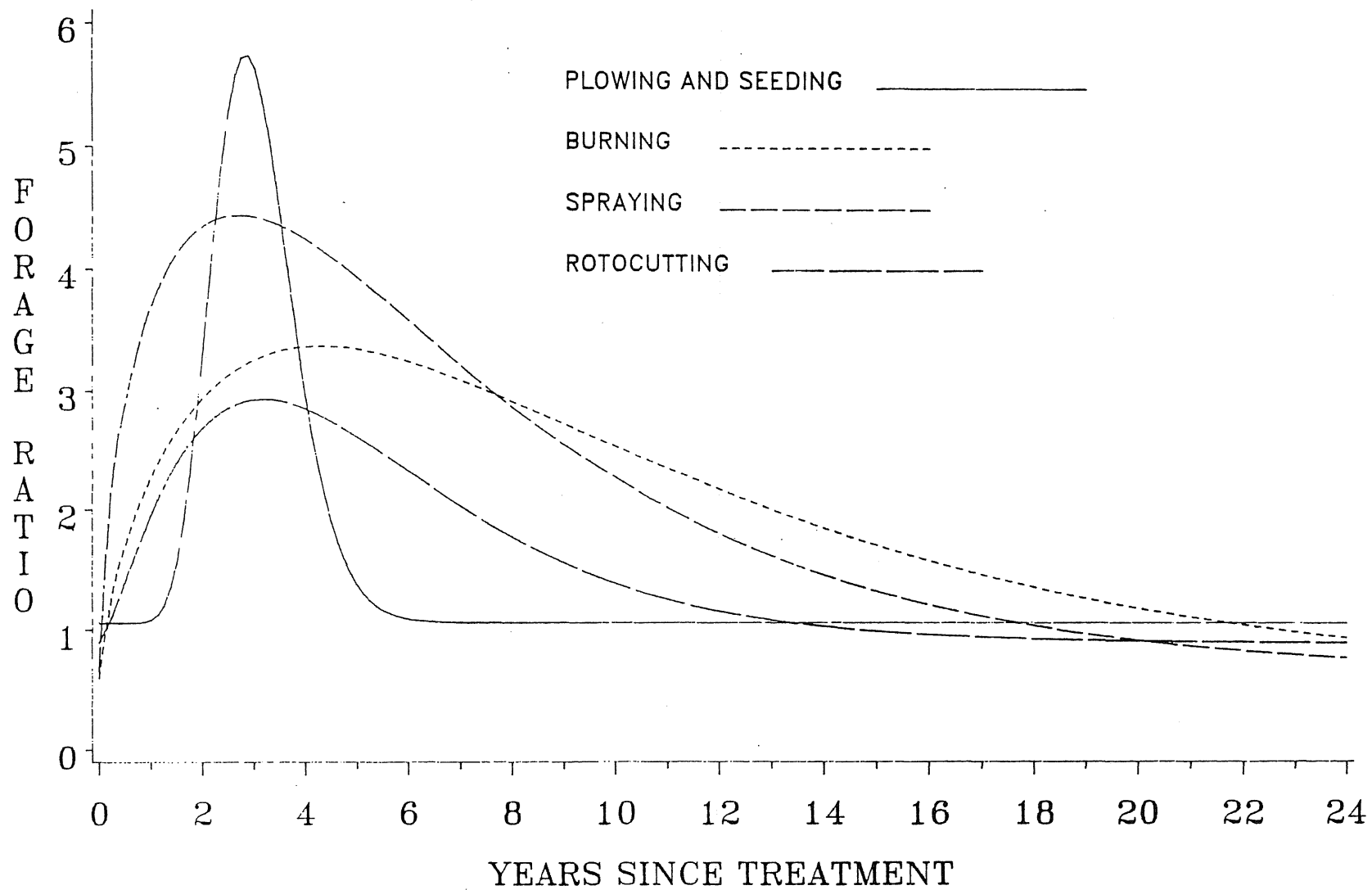


Figure 3. Production response to treatment.

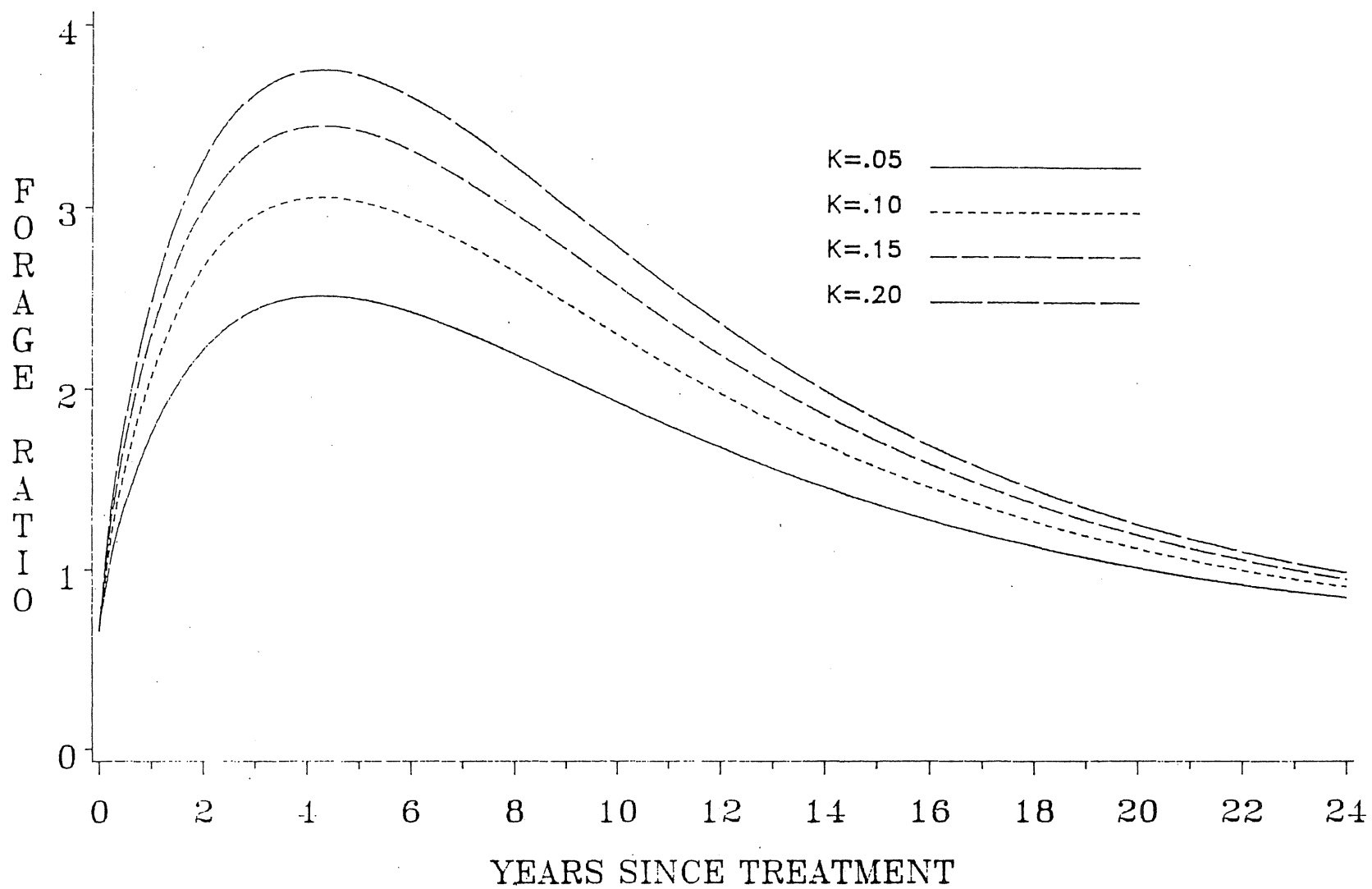


Figure 4. Production response to burning with different k values.

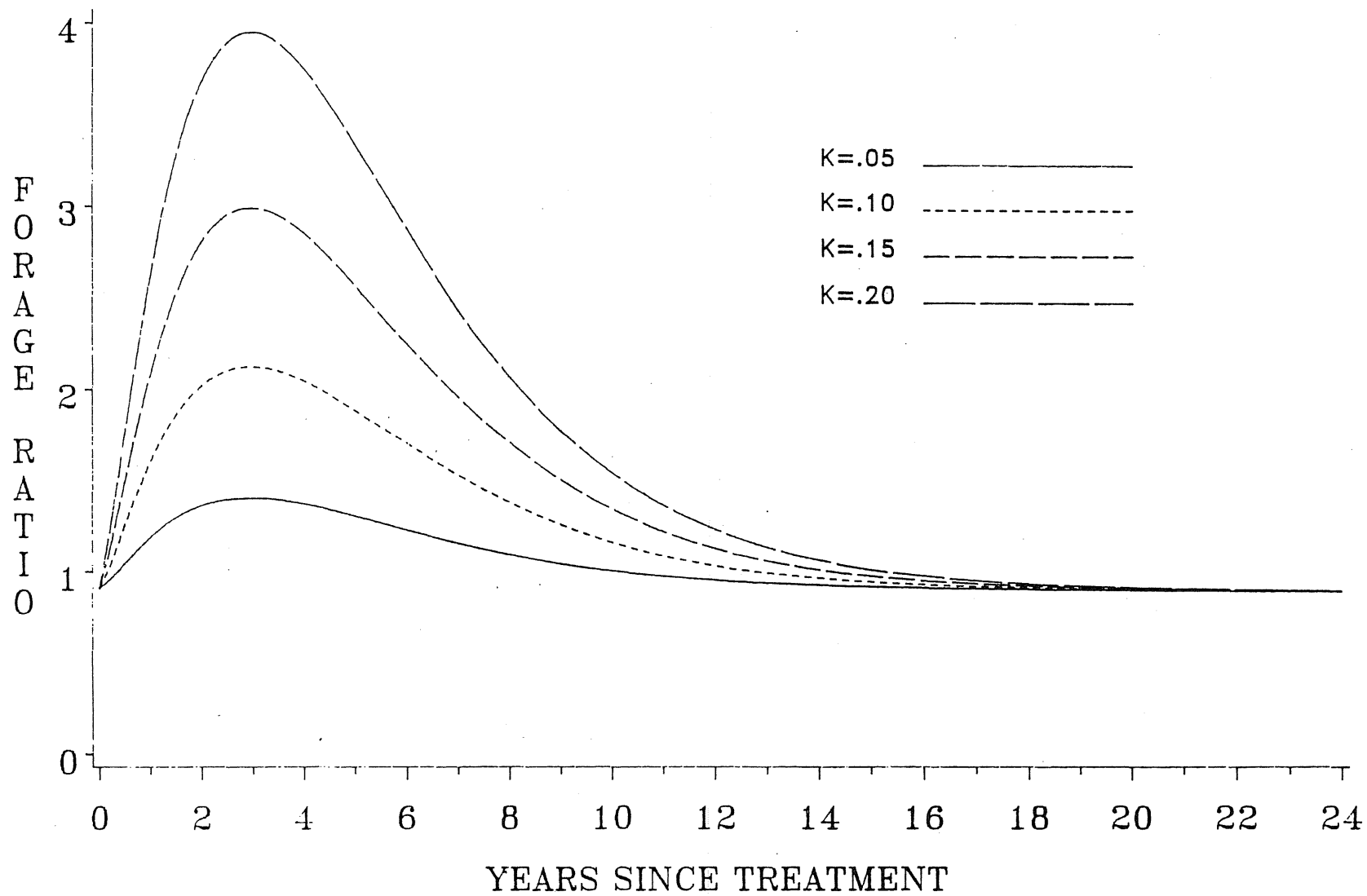


Figure 5. Production response to rotocutting with different k values.

it was inferred that all the variables had a significant influence except parameter θ for burning, where the t value was .89. The R^2 are .6640, .4990, .6321, and .6482 for spraying, rotocutting, burning, and plowing and seeding, respectively.

The response function for each treatment was also estimated using an alternative model specification $k^\beta(\alpha t^\gamma e^{\delta t} + \theta)$. This specification allows k to have an impact on long-term equilibrium, but the fit was not as good as for the previously specified function.

Some hypothesis tests show that:

1. There is a significant structural difference among these four treatments for the restricted model ($\beta=0$).
2. There is a significant structural difference between rotocutting and burning for the unrestricted model ($\beta \neq 0$).
3. Quantity of killed sagebrush does have significant influence on the unrestricted model in the case of burning and rotocutting.

For the details of these hypothesis tests, see Appendix E.

From the estimation results it was concluded that the response function reflected the changes in forage production after the treatment was applied and explained a high percentage of the variation in the observed values.

DP Solution

Solution of the recursive equation yields the optimal retreatment interval and expected present value of additional net returns for all combinations of states and stages. There are 750 states at each stage of the sagebrush treatment decision model. Before the results of the

DP model are discussed, two important assumptions made in developing the model should be stated:

1. The calf price transition probabilities obtained from the historical time-series analysis are valid for the future.

2. The subsequent responses to retreatments are identical with the initial response to treatment. For example, if an initial treatment was imposed at year t with a 10-year optimal retreatment interval, then after a retreatment application at year $t+10$, an identical response would begin to occur in year $t+11$ as the initial response in year $t+1$.

Tables 4, 5, and 6 summarize the results of the dynamic programming model, given the response function with the restriction $\beta=0$ for all four treatments, without the restriction $\beta=0$ for burning at different k levels, and without the restriction $\beta=0$ for rotocutting at different k levels, respectively.

Table 4 shows the results of comparing the four treatment methods, given the response function with the restriction $\beta=0$ and the specific treatment costs. From the results it was concluded that plowing and seeding was not economically feasible; rotocutting was only marginally feasible; and spraying and burning were economically feasible. The highest expected present value of additional net return was obtained with spraying. The results also show that as calf price increases (i.e., calf price in year $t-2$ is lower than in year $t-1$), the expected present value of additional returns would increase and the optimal retreatment interval would decrease, since an upward price trend usually implies higher expected future prices. The reverse

Table 4. Present value of the additional net returns (dollars/ha) and optimal retreatment intervals (years)^a generated by sagebrush treatment method, given specific treatment costs^b and previous calf price condition.

Previous Calf Price Condition		Treatment Method			
CP _{t-1}	CP _{t-2}	Spraying	Rotocutting	Burning	Plowing and Seeding
67.5	67.5	141.30 (8)	11.78 (13)	101.26 (10)	
67.5	82.5	137.35 (10)	11.12 (30) ^c	100.46 (9)	
67.5	97.5	135.36 (12)	11.06 (30) ^c	99.24 (9)	
67.5	112.5	134.68 (13)	11.04 (30) ^c	98.75 (9)	
67.5	127.5	134.36 (14)	11.03 (30) ^c	98.62 (9)	
82.5	67.5	145.32 (7)	13.15 (10)	102.22 (11)	
82.5	82.5	139.56 (8)	10.64 (14)	100.04 (11)	
82.5	97.5	135.51 (9)	9.92 (30) ^c	98.33 (11)	
82.5	112.5	132.28 (12)	9.93 (30) ^c	97.24 (11)	
82.5	127.5	130.94 (15)	9.95 (30) ^c	96.71 (11)	
97.5	67.5	148.96 (7)	13.94 (10)	104.40 (11)	
97.5	82.5	144.66 (7)	11.85 (11)	102.03 (11)	
97.5	97.5	138.52 (8)	9.78 (15)	99.84 (11)	NF ^d
97.5	112.5	134.22 (9)	8.92 (30) ^c	97.47 (12)	
97.5	127.5	130.95 (11)	9.09 (30) ^c	96.40 (12)	
112.5	67.5	151.49 (7)	14.65 (10)	106.22 (11)	
112.5	82.5	148.29 (7)	12.29 (11)	104.35 (11)	
112.5	97.5	144.50 (7)	10.86 (12)	100.82 (12)	
112.5	112.5	138.03 (8)	9.24 (16)	98.95 (12)	
112.5	127.5	133.60 (9)	8.89 (29)	97.39 (12)	
127.5	67.5	151.16 (7)	14.85 (10)	106.27 (11)	
127.5	82.5	150.00 (7)	12.65 (11)	103.55 (12)	
127.5	97.5	147.80 (7)	12.46 (11)	102.38 (12)	
127.5	112.5	144.72 (7)	11.02 (12)	100.76 (12)	
127.5	127.5	138.08 (8)	8.94 (27)	99.05 (12)	

^aOptimal retreatment intervals were in parentheses.

^bTreatment costs were presented in Table 2.

^cThe optimal retreatment interval might be longer than 30 years.

^dNot economically feasible.

relationship also holds with a downward price trend. For the given equal calf prices at years $t-2$ and $t-1$, a higher price combination would result in a lower expected present value of additional net returns and usually a longer optimal retreatment interval as compared to a lower price combination, since successive higher prices would imply lower expected future prices. For different previous calf price conditions, the expected present values and optimal retreatment intervals vary from \$130.94 to \$151.49 and 15 years to 7 years for spraying, and \$96.40 to \$106.27 and 12 years to 9 years for burning, respectively.

In Table 5, k varies from .05 to .25 in the case of burning, given the specific treatment cost. The results suggest that given the previous calf price condition, the expected present value would increase and optimal retreatment interval would decrease with the increasing k value. Since burning will still be an economically feasible treatment method with a .05 k value, it implies that imposing burning on an area with a sagebrush canopy cover above .05 is feasible.

The results of varying k value from .05 to .25 on rotocutting, given the specific treatment method, are presented in Table 6. Rotocutting was not an economically feasible method, with a k value below .15. The results also show a positive correlation between the expected present value and the quantity of killed sagebrush, and a negative correlation between the optimal retreatment interval and the quantity of killed sagebrush, other things equal.

Table 5. Present value of the additional net returns (dollars/ha) and optimal retreatment intervals (years)^a generated by burning, given specific treatment costs^b, previous calf price condition, and different k values,

Previous Calf Price Condition		Burning									
CP _{t-1}	CP _{t-2}	k=.05		k=.10		k=.15		k=.20		k=.25	
67.5	67.5	47.50	(11)	81.46	(10)	105.50	(10)	126.29	(9)	143.38	(9)
67.5	82.5	46.30	(12)	79.95	(10)	104.59	(9)	124.06	(9)	140.71	(9)
67.5	97.5	45.90	(12)	79.14	(10)	103.34	(9)	124.21	(8)	140.57	(8)
67.5	112.5	45.74	(12)	78.82	(10)	102.85	(9)	123.55	(8)	139.85	(8)
67.5	127.5	45.54	(13)	78.73	(10)	102.71	(9)	123.37	(8)	139.65	(8)
82.5	67.5	47.75	(12)	82.10	(11)	107.89	(10)	127.80	(10)	144.83	(10)
82.5	82.5	46.65	(12)	80.26	(11)	104.29	(11)	124.81	(10)	141.57	(10)
82.5	97.5	45.49	(13)	78.83	(11)	102.54	(11)	122.49	(10)	139.04	(10)
82.5	112.5	44.83	(14)	77.62	(12)	101.82	(10)	121.04	(10)	138.03	(9)
82.5	127.5	44.49	(15)	77.23	(12)	101.19	(10)	120.33	(10)	137.08	(9)
97.5	67.5	48.76	(12)	84.09	(11)	108.71	(11)	128.93	(11)	146.23	(11)
97.5	82.5	47.59	(12)	82.05	(11)	106.31	(11)	126.20	(11)	143.20	(11)
97.5	97.5	45.93	(13)	79.40	(12)	104.08	(11)	123.66	(11)	140.38	(11)
97.5	112.5	45.17	(13)	78.08	(12)	102.25	(11)	121.56	(11)	138.05	(11)
97.5	127.5	44.43	(14)	77.19	(12)	100.57	(12)	120.11	(11)	137.00	(10)
112.5	67.5	49.67	(12)	85.68	(11)	110.54	(11)	130.85	(11)	148.30	(11)
112.5	82.5	48.76	(12)	82.48	(12)	108.64	(11)	128.72	(11)	145.96	(11)
112.5	97.5	47.67	(12)	80.86	(12)	106.36	(11)	126.17	(11)	143.15	(11)
112.5	112.5	45.78	(13)	79.30	(12)	103.17	(12)	123.71	(11)	140.43	(11)
112.5	127.5	44.61	(14)	78.00	(12)	101.58	(12)	120.81	(12)	138.11	(11)
127.5	67.5	49.74	(12)	83.63	(12)	110.60	(11)	130.87	(11)	148.18	(11)
127.5	82.5	49.39	(12)	83.12	(12)	107.87	(12)	130.04	(11)	147.29	(11)
127.5	97.5	48.73	(12)	82.15	(12)	106.68	(12)	128.48	(11)	145.61	(11)
127.5	112.5	46.63	(13)	80.80	(12)	105.03	(12)	124.79	(12)	143.26	(11)
127.5	127.5	45.84	(13)	79.38	(12)	103.27	(12)	122.77	(12)	139.42	(12)

^aOptimal retreatment intervals are in parentheses.

^bTreatment costs are presented in Table 2.

Table 6. Present value of the additional net returns (dollars/ha) and optimal retreatment intervals (years)^a generated by rotocutting, given specific treatment costs^b, previous calf price condition, and different k values.

Previous Calf Price Condition		Rotocutting				
CP _{t-1}	CP _{t-2}	k=.05	k=.10	k=.15	k=.20	k=.25
67.5	67.5			13.41 (13)	63.00 (8)	120.53 (7)
67.5	82.5			12.73 (30) ^c	60.62 (10)	117.38 (8)
67.5	97.5			12.61 (30) ^c	59.24 (16)	115.79 (9)
67.5	112.5			12.57 (30) ^c	59.04 (30) ^c	115.48 (9)
67.5	127.5			12.56 (30) ^c	59.02 (30) ^c	115.40 (9)
82.5	67.5			14.36 (10)	63.76 (8)	122.29 (7)
82.5	82.5			12.16 (14)	62.04 (8)	119.18 (7)
82.5	97.5			11.36 (30) ^c	58.46 (11)	114.39 (9)
82.5	112.5			11.30 (30) ^c	57.18 (30) ^c	112.85 (10)
82.5	127.5			11.29 (30) ^c	57.14 (30) ^c	111.67 (13)
97.5	67.5			16.89 (9)	69.47 (7)	125.04 (7)
97.5	82.5			14.18 (10)	63.25 (8)	121.82 (7)
97.5	97.5	NF ^d	NF ^d	11.41 (14)	59.87 (9)	116.14 (8)
97.5	112.5			10.23 (30) ^c	57.25 (11)	112.66 (10)
97.5	127.5			10.35 (30) ^c	55.77 (30) ^c	110.76 (11)
112.5	67.5			17.78 (9)	71.84 (7)	127.39 (7)
112.5	82.5			14.80 (10)	64.74 (8)	124.96 (7)
112.5	97.5			12.93 (11)	63.27 (8)	122.04 (7)
112.5	112.5			10.82 (15)	59.47 (9)	115.66 (8)
112.5	127.5			10.27 (29)	56.51 (11)	112.00 (9)
127.5	67.5			15.39 (10)	66.31 (8)	127.81 (7)
127.5	82.5			15.24 (10)	65.83 (8)	126.88 (7)
127.5	97.5			14.96 (10)	64.93 (8)	125.10 (7)
127.5	112.5			12.06 (12)	60.34 (9)	117.54 (8)
127.5	127.5			10.50 (16)	59.51 (9)	115.69 (8)

^aOptimal retreatment intervals are in parentheses.

^bTreatment costs are presented in Table 2.

^cThe optimal retreatment interval might be longer than 30 years.

^dNot economically feasible.

CHAPTER 5

CONCLUSIONS

Sagebrush management strategies have been the subject of considerable research and application for a long time. However, only a few studies deal with economic considerations of these strategies. The previous economic analysis completed simply computed the present value of the net benefits (Kearl and Brannan, 1967), or calculated the internal rate of return (Nielson and Hinckley, 1975) from a single treatment of sagebrush, assuming that the response to the treatment was constant over a prespecified effective treatment life.

This study conducted an economic comparison among four Wyoming big sagebrush control methods--spraying with 2,4-D, burning, plowing and seeding, and rotocutting. Production of perennial grasses was measured on experimental plots in southwestern Montana 12 years during the period 1963-1986. The data were used to estimate a nonlinear production response function. Control of sagebrush is a stochastic dynamic problem and as such the problem was formulated within a stochastic dynamic programming framework. The economic choice criterion was the expected present value of additional net returns from sagebrush treatment. Decision alternatives included in the DP model were keeping or retreating the sagebrush. The state variables were years since treatment and the expected value of forage yield per AUM which was defined as a function of calf price. Based upon a

statistically estimated second-order autoregressive difference equation, the calf price transition probability distribution was developed. Optimal retreatment intervals as well as control method selection were model outputs.

Burning and spraying as control methods of Wyoming big sagebrush were found economically feasible. Spraying was the most profitable. Rotocutting was only marginally feasible, and plowing and seeding was not feasible.

From the study results it was also concluded that in addition to treatment method, treatment cost, and the quantity of sagebrush killed, the present value of additional net return and optimal retreatment interval also depend upon previous calf price trend. For two combinations of previous calf prices with equal mean, an upward trend would result in a higher present value of additional net return and a shorter optimal retreatment interval as compared to a downward trend.

The results of this study are consistent with the conclusion reached by the USFS (1973) that "mechanical methods are not considered to be a viable alternative" (p. 54), and also consistent with Neilsen and Hinckley's (1975) suggestion to the extent that plowing and seeding was not economically feasible, but not consistent with Kearl and Brannan's (1967) claim that plowing and seeding was the most productive method.

Any study of this type has limitations. The major potential limitation of the study is that the decision rules are valid only to the extent that the subsequent responses to retreatment are identical

to the initial treatment response. This assumption might be questionable because of the largely unknown nature of the biological response process.

A second limitation of this study is that the study plots were not actually grazed by livestock, but forage production was estimated by clipping, and thereby AUMs of production were estimated. Therefore, a prudent concern is whether this approach provides accurate estimates under typical grazing conditions.

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APPENDICES

APPENDIX A

ORIGINAL DATA

Table 7. Production level of perennial grasses with spraying (kg/ha).

Year	Replication			
	1	2	3	4
1964	660.7	721.5	635.4	473.9
1965	566.7	560.3	735.1	618.5
1966	118.6	329.9	160.9	250.5
1967	811.2	833.6	880.6	482.1
1970	280.3	546.2	462.1	277.5
1976	169.5	182.1	431.4	135.5
1977	128.0	222.8	327.5	54.9
1978	358.4	661.1	379.7	389.2
1981	517.8	404.1	303.0	324.7
1985	123.2	72.7	58.1	81.2
1986	103.8	136.9	91.0	134.5

Table 8. Production level of perennial grasses with burning (kg/ha).

Year	Replication			
	1	2	3	4
1965	314.1	402.9	352.3	230.7
1966	82.6	144.6	103.8	85.6
1967	630.8	822.9	678.9	901.0
1970	538.6	563.4	395.5	439.4
1976	133.5	195.2	183.3	322.4
1977	131.2	251.2	171.8	291.9
1978	478.0	601.5	419.2	605.5
1981	577.8	758.0	541.9	954.7
1985	181.6	114.0	103.5	273.4
1986	101.4	119.8	159.8	235.0

Table 9. Production level of perennial grasses with rotocutting (kg/ha).

Year	Replication			
	1	2	3	4
1964	570.6	294.9	223.0	495.0
1965	330.5	259.4	278.0	526.9
1966	218.0	134.1	55.7	37.1
1967	430.1	780.6	405.7	933.1
1970	215.7	463.3	287.9	272.3
1976	63.6	185.3	118.9	109.4
1977	46.2	180.1	67.6	104.3
1978	206.4	238.8	227.0	271.6
1981	338.9	559.3	310.1	399.0
1985	82.8	195.1	132.9	150.8
1986	214.3	182.0	225.7	156.5

Table 10. Production level of perennial grasses with plowing and seeding (kg/ha).

Year	Replication			
	1	2	3	4
1964	69.1	143.9	50.5	67.0
1965	262.8	554.7	546.6	600.7
1966	101.8	150.1	264.4	340.2
1967	544.4	795.3	592.2	509.3
1970	212.5	300.6	216.9	176.6
1976	142.2	37.5	364.2	148.9
1977	71.9	69.9	354.8	214.1
1978	245.3	131.2	658.1	378.3
1981	217.8	220.9	132.5	225.3
1985	126.7	96.7	106.6	91.6
1986	121.8	195.5	168.4	233.7

Table 11. Production level of perennial grasses on control (kg/ha).

Year	Replication			
	1	2	3	4
1964	152.4	198.6	243.6	131.3
1965	133.1	184.8	187.7	84.2
1966	16.5	56.9	48.3	30.4
1967	145.6	255.5	174.5	248.7
1970	147.1	248.4	145.9	88.9
1976	102.3	153.3	129.2	83.4
1977	169.5	53.3	98.0	48.6
1978	506.0	303.9	216.7	223.0
1981	370.1	456.2	365.8	236.6
1985	174.2	148.9	82.0	113.3
1986	355.4	181.1	235.0	201.0

Table 12. Calf price (dollars/100 lbs.)

Year	Current Dollars	1986 Dollars ^a
1974	30.40	67.60
1975	30.80	62.75
1976	36.30	69.92
1977	41.40	74.90
1978	70.30	118.15
1979	89.80	135.65
1980	76.80	102.19
1981	62.70	75.59
1982	60.30	68.50
1983	62.40	68.67
1984	60.90	64.27
1985	62.20	63.40
1986	62.60	62.60

^aAdjusted for inflation from 1974 to 1986 by CPI (Economic Report of the President, 1987)

Table 13. Sagebrush canopy cover.

Treatment	Replication	1963	1964	1965
Spraying	1	.1333333	.0100000	
	2	.1430000	.0100000	
	3	.1673333	.0040000	
	4	.1870000	.0124000	
Burning	1		.1470000	.0000000
	2		.2120000	.0000000
	3		.0836666	.0000000
	4		.1366666	.0000000
Rotocutting	1	.1773333	.0083333	
	2	.1416666	.0100000	
	3	.1253333	.0153333	
	4	.1826666	.0088888	
Plowing and Seeding	1	.1863333	.0266666	
	2	.0870000	.0184000	
	3	.1203333	.0065000	
	4	.1593333	.0190000	

APPENDIX B

DERIVATION OF THE SIGNS OF THE
RESPONSE FUNCTION PARAMETERS

For the extremum to be a maximum at $t = -\gamma/\delta$, the sign of equation (B.04) should be negative. Hence, the sign of parameter α should be positive under the conditions $\beta > 0$, $\gamma > 0$ and $\delta < 0$.

5. Since θ is the long-term equilibrium level of forage response, its sign should be positive.

Thus, the desirable signs of the parameters in the response function are: $\alpha > 0$, $\beta > 0$, $\gamma > 0$, $\delta < 0$ and $\theta > 0$.

APPENDIX C

THE CALCULATION OF EQUIVALENT WEIGHT OF CALVES
AND AVERAGE COST OF RAISING A CALF

The calculation of equivalent weight of calves and the average cost of raising a calf is presented in this appendix.

To simplify the model, weights of cows and bulls were adjusted to equivalent weight of calves by the cattle to calf price ratio.

If we assume:

1. There is a herd on 100 cows;
2. The culling rate, replacement rate, and weaning rate are .16, 0.17, and .85 respectively;
3. The ratio of bulls to cows is .04 and bulls are kept for 4 years; and
4. The average weights of cows, bulls, and calves are 1100, 1500, and 450 pounds, respectively.

Then, the equivalent weight of calves would be

$$EW = .8157 \times (1100 \times .16 + 1500 \times .01) + 450 \times (.85 - .17) = 462$$

where .8157 is the average cattle to calf price ratio from 1974 to 1986.

The average cost of raising a calf was obtained using the following formula:

$$\overline{CP} \times EW - AC = \overline{GF} \times LGS \quad (C.01)$$

where

$\overline{CP}$ = average calf price per 100 lbs. from 1974 to 1986 in 1986 dollars, which is \$79.65

EW = equivalent weight of a calf, which is 4.62 hundred lbs.

AC = average cost of raising a calf

$\overline{GF}$ = average grazing fee from 1974 to 1986 in 1986 dollars, which is \$11.73

LGS = length of grazing season, which is 9 months

Thus, the calculated value of AC in equation (C.01) is \$262.41.

APPENDIX D

STATISTICAL TEST FOR NORMAL DISTRIBUTION OF
CALF PRICE EQUATION RESIDUALS

The statistical test for the hypothesis that the residuals from the calf price equation are normally distributed is presented in this appendix.

The test statistic, fully described in Kmenta (1986, pp. 265-267), is

$$n[b_1/6 + (b_2 - 3)^2/24] \sim \chi^2_2 \quad (D.01)$$

where n is the number of observation, b_1 and b_2 are the estimates of β_1 and β_2 which are defined as

$$\beta_1 = \mu_3/\mu_2^{3/2} \text{ and } \beta_2 = \mu_4/\mu_2^2$$

where μ_2 is the second moment, variance; μ_3 is the third moment, skewness; and μ_4 is the fourth moment, kurtosis. They may be obtained using PROC MEANS statement in the SAS/ETS software package.

The following values were obtained for the calculation of the value of the test statistic (D.01):

$$\begin{aligned} \mu_2 &= 206.324, & \mu_3 &= 1.63486, & \mu_4 &= 3.36981 \\ b_1 &= .000000304306, & b_2 &= .00007916 \end{aligned}$$

The value of the test statistic (D.01) in this case is 4.125, whereas the tabulated value of χ^2_2 at 5% level of significance is 5.991. The hypothesis of normality at the 5% level would not be rejected.

APPENDIX E

HYPOTHESIS TESTS ON RESPONSE FUNCTION

Some hypothesis tests on the response function are presented in this appendix.

The test statistic used is

$$F_{v, q, n-k} = \frac{(SSE_r - SSE_{ur})/q}{SSE_{ur}/n-k} \quad (E.01)$$

where SSE_r and SSE_{ur} are the sum of square residuals in the restricted and unrestricted models respectively, n is the number of observations, q is the number of restrictions, k is the number of the parameters estimated in the unrestricted model, and v is the significance level. All statistical tests are based upon a significance level of .05.

The measurements needed for calculating the value of the test statistic (E.01), in addition to those presented in Table 3, are presented in Table 14.

Table 14. Response function statistics (2).^a

Treatment	α	β	γ	δ	θ	SSE	R^2
Cross Burning and Rotocutting ^b	6.47422 (1.72)	.73013 (2.29)	1.06423 (2.67)	-.298103 (-2.83)	.98950 (4.28)	47.54433	.5272
Cross All of Four Treatments ^c	1.90881 (4.85)		2.74048 (4.33)	-.879551 (-4.31)	1.21879 (10.54)	201.63429	.4856

^aThe numbers in the parentheses are the t values.

^bFunction was estimated without restriction $\beta=0$.

^cFunction was estimated with restriction $\beta=0$.

1. To test for a significant structural change among the four forage responses with the restricted model ($\beta=0$), the null hypothesis

is

$$H_0: \alpha_S = \alpha_B = \alpha_R = \alpha_P$$

$$\gamma_S = \gamma_B = \gamma_R = \gamma_P$$

$$\delta_S = \delta_B = \delta_R = \delta_P$$

$$\theta_S = \theta_B = \theta_R = \theta_P$$

The measurements for calculating the value of the test statistic (E.01) are

$$SSE_r = 201.63429$$

$$SSE_{ur} = 47.01323 + 29.05609 + 13.92577 + 49.39919 \\ = 139.39428$$

$$q = 12$$

$$n = 172$$

$$k = 16$$

The value of the test statistic (E.01) is then 5.80, whereas the tabulated value of $F_{.05,12,156}$ is 1.82. So the null hypothesis that there is no structural change among these four forage responses would be rejected.

2. To test the hypothesis that the quantity of killed sagebrush has a significant influence on the model for rotocutting, the null hypothesis is

$$H_0: \beta_R = 0$$

The measurements for calculating the value of the test statistic (E.01) are

$$SSE_r = 29.05609$$

$$SSE_{ur} = 25.81935$$

$$q = 1$$

$$n = 44$$

$$k = 5$$

The value of test statistic (E.01) is then 4.89, whereas the tabulated value of $F_{.05,1,39}$ is 4.10. So the hypothesis that the quantity of killed sagebrush has no significant influence on the model for rotocutting would be rejected.

3. To test the hypothesis that the quantity of killed sagebrush has a significant influence on the model for burning, the null hypothesis is

$$H_0: \beta_B = 0$$

The measurements for calculating the value of the test statistic (E.01) are

$$SSE_r = 13.92577$$

$$SSE_{ur} = 12.37374$$

$$q = 1$$

$$n = 40$$

$$k = 5$$

The value of the test statistic (E.01) is then 4.39, whereas the tabulated value of $F_{.05,1,35}$ is 4.12. Therefore, the hypothesis that the quantity of killed sagebrush has no significant influence on the model for burning would be rejected.

4. To test the hypothesis that there is a significant structural change between the two forage responses (burning and rotocutting) for the unrestricted model ($\beta \neq 0$), the null hypothesis is

$$H_0: \alpha_B = \alpha_R$$

$$\beta_B = \beta_R$$

$$\gamma_B = \gamma_R$$

$$\delta_B = \delta_R$$

$$\theta_B = \theta_R$$

The measurements for calculating the value of the test statistic (E.01) are

$$SSE_r = 47.54433$$

$$\begin{aligned} SSE_{ur} &= 25.81935 + 12.37374 \\ &= 38.19309 \end{aligned}$$

$$q = 5$$

$$n = 84$$

$$k = 10$$

The value of the test statistic (E.01) is then 3.6236, whereas the tabulated value of $F_{.05,5,74}$ is 2.35. Therefore, the hypothesis that there is no significant structural change between the two forage responses (burning and rotocutting) for the unrestricted model ($\beta \neq 0$) would be rejected.