Increasing Grass Production by Reducing Overstory Competition -- An Optimization Procedure

John A. Tanaka

ABSTRACT: The purpose of this paper is to investigate an optimization procedure for estimating the intensity of overstory reduction when the biological goal is to increase forage production and the economic goal is to maximize ranch profits. The procedure is based on the decision-maker's ability to accurately estimate production, cost, and benefit functions for specific range improvements.

INTRODUCTION

Research on the use of crested wheatgrass (Agropyron desertorum and A. cristatum) for rangeland seeding has focused primarily on biological and economic feasibility. The success of this research, however informal, can be judged in terms of the acreages and diversity of locales in which crested wheatgrass has been seeded. In many situations these seeded ranges have overstory species such as big sagebrush (Artemisia tridentata), pinyon pine (Pinus edulis) or juniper (Juniperus spp.) becoming re-established. The purpose of this project is to develop a procedure for estimating the optimal rate of overstory control for increasing understory forage production.

The procedure will be developed in conjunction with work by Allen Torell in the Department of Economics at Utah State University (Torell and Godfrey 1986). The goal of our research is to answer on-the-ground management questions for investment decisions. Our projects will form a package to provide range managers with an analytical framework for decision-making. In general, the manager should be able to decide (1) if a forage stand is depleted enough to warrent control of the re-establishing overstory species, (2) the optimal kill rate target (with implications as to the selected improvement methods), and (3) how long before recontrol would be needed--which completes the decision cycle. This paper will describe the rationale and principal components of the proposed procedure. Implications for research and management will also be discussed.

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Range Economics and Decision-making

Range economics has been defined as the application of "the principles of economics and range management simultaneously to determine the economic consequences of decisions involving the use, development, and/or preservation of rangelands" (Workman 1986). Economics deals with the allocation of scarce resources among competing uses.

In this context, decisions to allocate limited investment capital among alternative choices need to be made within the context of a given decision-making unit (e.g. an individual ranch). Many of the problems associated with the valuation of range improvement benefits can be avoided by using the ranch as the decision-making unit of analysis for range improvement decisions (Workman 1986).

If the individual rancher is the decision-maker, the procedure should provide useful information for ranch investment decisions when the biological goal is to increase desirable forage production by reducing the competing overstory, and the economic goal is to maximize profits. Specifically, the results should indicate how much capital to invest in order to obtain an optimal target kill rate of the overstory species. The initial investment will help determine which of the alternative methods and intensities of treatment are economically feasible. Each feasible method must then be analyzed under other decision criteria (e.g. political, sociological, biological, risk). The economically optimal kill rate will result in maximum expected net returns (profits) to the ranching operation.

In a multiple use decision-making context, if the target kill rate is less than that determined to be optimal for the ranch, then the resource manager will have information on what is being given up in terms of economic efficiency. Any kill rate other than the optimal rate will result in lower profit levels and is, therefore, a less efficient use of capital.

The procedure is not designed to indicate what should be the socially optimal decision on public lands. The usefulness of this marginal evaluation procedure to public land managers will depend on their need for additional information. Maximizing profit on a ranch is rarely a goal of the public land manager. Therefore, the procedure probably will not be useful for deciding the intensity of a given range improvement practice, but it will, nevertheless, provide useful information for the decision-making process. It identifies the trade-off between the loss of economic efficiency of a non-optimal policy decision vs. the economically efficient improvement policy. Through its application, the effects of a given decision on an individual permittee's economic well-being can be assessed.

Rationale for the Proposed Analytical Procedure

What to do with established stands of crested wheatgrass is a central issue from a business management and investment viewpoint. In other words, once an investment is in the rancher's portfolio, the relevant decision is what to do with it. In terms of a crested wheatgrass stand subject to an increasing population of an overstory species such as big sagebrush, at least three options are available from a ranch perspective: (1) to allow the overstory species to mature resulting in less usable forage through time, (2) to reduce the overstory species by investing more capital and thereby increasing forage production, and (3) to sell, lease, or otherwise divest in the seeding and use the released capital in alternative uses. For an operating ranch the second alternative is only desirable if additional forage is needed to balance yearlong forage supply and demand, increase herd size, or replace more expensive feed (Plath 1954, Workman 1986). Otherwise, investment to maintain an unnecessary seeding (for livestock production) will result in no economic benefit to the investor.

Once the decision is made that additional investment (i.e. overstory reduction) is necessary, the procedure being developed will indicate the optimal kill rate for a given set of relative prices. Examples of overstory reductions resulting in an increase in understory production are abundant in the literature. These examples span vegetation types as well as improvement methods within a vegetation type. However, most of this type of research has focused on finding a significant difference between the treatment and a control. In order to develop a functional relationship between overstory control and understory production, multi-rate experimental designs are required. The estimated function could then be used in deciding how intensively similar stands should be treated in order to benefit both the understory species and the ranch business enterprise.

BASIS FOR THE PROPOSED ANALYTICAL PROCEDURE

The baseline information necessary for the analytical procedure is derived from published research results and the concepts of economics and range management. For example, the underlying production function must accurately predict forage responses for given levels of overstory kill. If the predicted response is accurate, then the economic model will supply useful information for decision-making provided that all economic relationships can be estimated. Therefore, the procedure must be based on known and proven biological and economic relationships. The procedure will be developed using crested wheatgrass/big sagebrush interactions as an example, but the technique will be applicable to other vegetation types where overstory competition limits desirable understory production.

Crested Wheatgrass/Big Sagebrush Relationships

Controlling woody overstory species to increase production of desirable forage and browse plants has been a guiding principle of range management since its beginnings. Robertson (1947) concluded that if sagebrush stands of forty percent cover could "...be reduced to spacing of more than a meter apart, a release from competition will occur which will be progressively better for growth of grasses as more brush is eradicated." Results from a southern Idaho study designed to evaluate crested wheatgrass production when sagebrush was controlled at various rates indicated that the last remaining sagebrush plant suppressed grass production the most, and that each preceeding sagebrush plant suppressed relatively less production (Hull and Klomp 1974).

The general crested wheatgrass/big sagebrush relationship will be discussed in terms of both static and dynamic interactions. The static model views crested wheatgrass production as an average yearly amount in relation to the amount of big sagebrush killed. The dynamic model views crested wheatgrass production as a yearly average that changes as a result of changes in big sagebrush parameters (e.g. density, age structure, canopy cover). In each case, the average production can be associated with a range of values indicative of yearly or seasonal variations in production.

The two model formulations provide the framework for determining the significant variables to be included in the production function. While the dynamic model formulation is more meaningful, the procedure will be developed in this project as a static model because of data limitations. The discussion of dynamic relationships is included to provide the link to the procedure being developed by Torell and Godfrey (1986).

Static Crested Wheatgrass/Big Sagebrush Relationships.--The static production function will relate crested wheatgrass production to any of several variables (e.g. big sagebrush characters, climatic parameters). The relationship between crested wheatgrass production and big sagebrush canopy cover has been estimated as a linear function (Rittenhouse and Sneva 1976). The form of the production function has been estimated for different vegetation types as curvilinear (Pase 1958, Halls and Schuster 1965, Jameson 1967, Clary 1971, Scifres et al. 1982). Several authors have also estimated curvilinear functions relating understory production to overstory basal area (Halls and Schuster 1965, Woods et al. 1982, Wolters et al. 1982). Bartolome and Heady (1978) concluded that the hypothesis of a negative correlation of big sagebrush density and grass production should be rejected. These approaches yield estimates of production either for an average year or for a year similar to the data collection year.

Yearly variations in herbage production were accounted for based on monthly precipitation and temperature by Sneva (1977). He found that mature yields of a given crested wheatgrass stand were correlated best with monthly precipitation for eight consecutive months beginning in July, August, or September of the previous year. This approach allowed for prediction of current mature yields based on information obtainable prior to the start of the growing season. Clary and Jensen (1981) related herbage production potential to annual precipitation and tree cover. This model provided the type of production surface expected in the crested wheatgrass/big sagebrush production function. It predicted the expected response from overstory control as well as the range of responses that were expected based on yearly fluctuation.

Research designed to specifically estimate the relationship between crested wheatgrass production and such factors as big sagebrush canopy cover, density, or age structure are relatively rare. Hull et al. (1952) and Alley (1956) measured the response of native grasses to big sagebrush control. Their data indicated that grass production increased relatively faster as more big sagebrush was killed. Hull and Klomp (1974) found that killing the last twenty-five percent of a big sagebrush stand was at least as effective as killing the first seventy-five percent in terms of increased crested wheatgrass production.

Dynamic Crested Wheatgrass/Big Sagebrush Relationships.--The dynamic relationship determines project life and the production time stream. Economic feasibility analyses that use constant production values over the life of the project discount the effects of dynamic factors which affect overstory re-establishment (e.g. stocking rate). Initial kill may have the greatest impact on sagebrush re-establishment (Johnson 1958, Johnson and Payne 1968). In Nevada, Frischknecht and Bleak (1957) found that most of the sagebrush in a seeding became established within two years following control. In Oregon, Bartolome and Heady (1978) found that sagebrush re-establishment was highest in the first year after treatment. Big sagebrush reached pre-treatment densities, at some point in time, regardless of initial kill rate (Johnson 1969, Bartolome and Heady 1978).

As with initial kill rate results, the literature indicates that estimated project life varies widely. In Wyoming, Johnson (1969) found that increased native herbage from big sagebrush control was nullified within six years. Thilenius and Brown (1974), also in Wyoming, found that native herbage production was below pre-treatment levels after ten to eleven years. In southern Idaho, Hull and Klomp (1966) found that crested wheatgrass stands remained productive after thirty years. Crested wheatgrass stands were also found to have thickened and spread because of a lack of competing vegetation, rough soil surface, and soil movement (Hull and Klomp 1967). Harniss and Murray (1973) supported the conclusion that sagebrush control evaluations should be done on a subspecies basis. Variation in the results may be alleviated by using a homogeneous site for model development.

A dynamic relationship between overstory and understory has been formulated for the pinyon/juniper vegetation type. The biological effects of recovery rate after control and the forage depletion rate have been used in economic models designed to estimate the optimal time between control actions (Cotner 1963a, Jameson 1971, Burt 1971).

Biological Case Study.--Research conducted in southern Idaho by Hull and Klomp (1974) was selected for development of the big sagebrush/crested wheatgrass production function. This study was conducted in two different sagebrush communities -- basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) near Holbrook and Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) near Twin Falls. Annual precipitation for the Holbrook and Twin Falls sites averaged sixteen and nine inches, respectively. Complete site descriptions can be found in Hull and Klomp (1974).

The study design was to reduce big sagebrush stands, with an initial density of twenty plants per 100 sq ft, by 0, 50, 75, and 100-percent in each age class. Crested wheatgrass production response to big sagebrush kill rate is shown in Table 1. Because no significant difference in production response was found among burning, spraying, and hand-grubbing treatments within each kill rate, data shown in Table 1 represent yearly averages for 1965-1970. The shape of the production relationship (averaged over 1967 through 1970 data) is shown to be a curve increasing at an increasing rate (Fig. 1). The shape of this production relationship is one crucial factor for accurate determination of the optimal kill rate of big sagebrush. The convex shape is also consistent with the curve hypothesized by Clary and Jensen (1981) for the pinyon/juniper vegetation type.

Economic Analysis of Overstory Reduction Projects

The use of economic theory in the process of natural resource decision-making has been of

Table 1.--Pounds of air-dry crested wheatgrass production at four intensities of big sagebrush control at Holbrook and Twin Falls, Idaho. Adapted from Hull and Klomp (1974).

Location and control rate	1965	1966	1967	1968	1969	1970
percent	-------pounds of yield[1]-------					
Holbrook:						
0	627	397	555	503	400	502
50	638	395	850	705	511	668
75	672	505	1042	954	757	961
100	642	581	1593	1468	1152	1874
Twin Falls:						
0	498	210	415	250	452	652
50	446	188	535	315	551	827
75	499	201	589	389	597	977
100	458	231	777	531	763	1250

[1]Yields are expressed as an average of burning, spraying and handgrubbing.

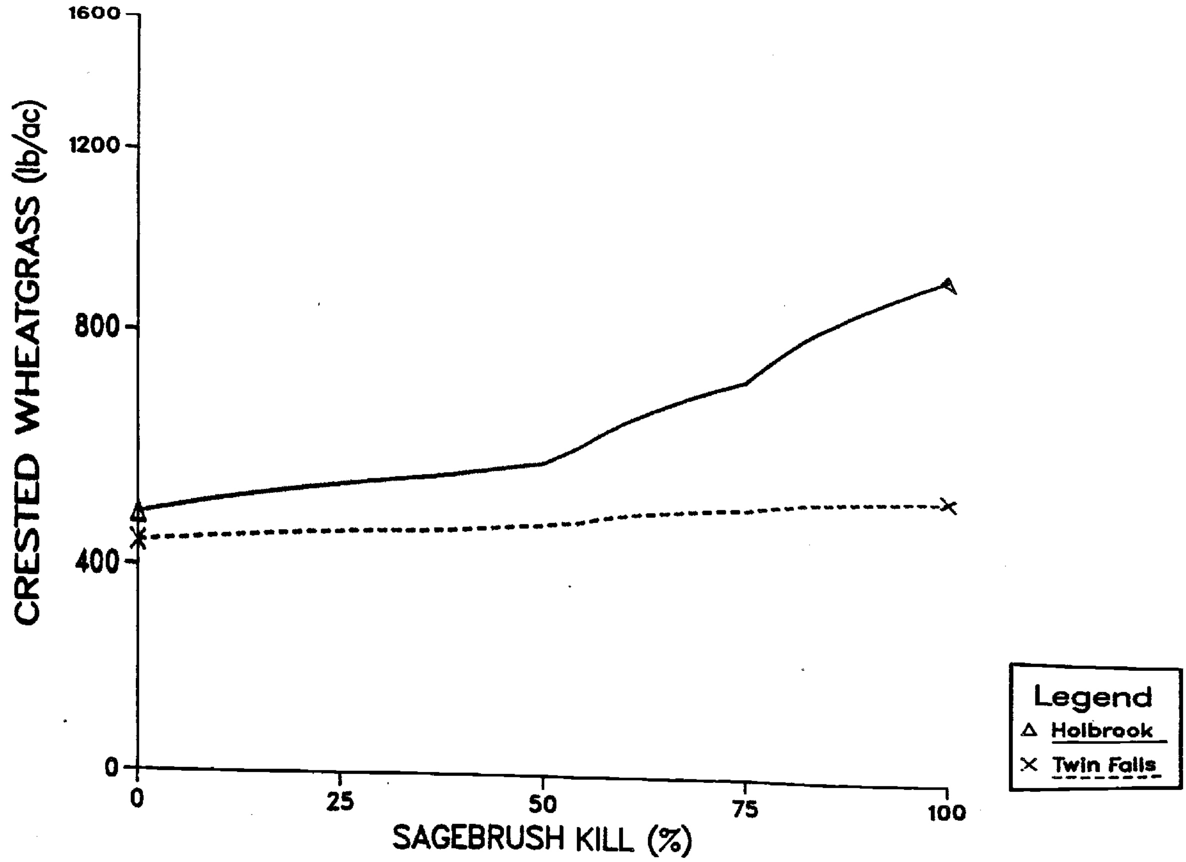

Figure 1.--Yields of crested wheatgrass under 0, 50, 75, and 100 percent big sagebrush reductions; average of four years (1976-1970). Adapted from Hull and Klomp (1974).

interest to researchers. Although the theory underlying economic research may not be of interest to resource managers, results from such studies will be useful. In the present model, determination of an economically optimal intensity of a range improvement must be based on this theory.

Static and dynamic procedures have been developed to economically analyze range improvements. All such methodologies have been concerned with estimating biological responses and associated benefits and costs attributed to the project. Economic analyses have been conducted for individual projects (Caton and Beringer 1960, Gardner 1961, Krenz 1962, Sassaman and Fight 1975, Godfrey 1979, Godfrey et al. 1979); optimal combinations of animal species (Upchurch 1954, Hopkin 1954); optimal grazing intensity (Hooper and Heady 1970, Pearson 1973); and optimal timing for recontrol of woody plants (Krenz 1962, Cotner 1963b, Jameson 1971, Burt 1971, Perrin 1972, Stevens and Godfrey 1972, Dixon and Howitt 1980). Analytical methods used to evaluate individual projects have led to the development of techniques for estimation of average (i.e. typical) control costs and expected benefits.

Economic analyses of crested wheatgrass seedings have been largely based on individual project analysis, focused on obtaining costs and benefits of the practice (Lloyd 1959, Caton and Beringer 1960). The analysis usually proceeds by discounting future net benefits to present value (less initial investment) in order to determine economic feasibility (Workman 1986). Costs have been reported in terms of physical units (e.g. labor, materials) for specific practices (McCorkle et al. 1964, Ralphs and Busby 1979, Sonnemann et al. 1981, Young et al. 1982). The cost approach will be useful for conducting (ex ante) analyses of proposed projects on similar sites. Forage benefits have been estimated as the value of substitute products (e.g. hay, private leased land), capitalization of permit values, and the value of additional livestock produced (Workman 1986, Wagstaff 1983). Care must be used in estimating benefit values by any of these methods because their validity will depend on what the additional forage does for the year-round ranching operation (Workman 1986). In any event, once the benefit and cost data have been estimated, there are three basic methods of determining economic feasibility (Workman 1986): (1) internal rate of return (IRR), (2) benefit/cost ratio (B/C), and (3) present net worth (PNW). Economic feasibility has been determined using IRR by Krenz (1962), Gray (1965), Nielsen et al. (1966), Sassaman (1972), and Sassaman and Fight (1975). The IRR method identifies the discount rate that forces the present value of all costs to equal the present value of all benefits (Workman 1981, 1986). The IRR can then be compared to the investor's opportunity cost and the economic feasibility (IRR greater than required rate of return in this case) determined on an individual basis. Lloyd and Cook (1960), Gray (1965), Gray et al. (1965), and Sassaman (1972) used the IRR method to determine net returns necessary to cover project costs at different required rates of return.

On the other hand, both B/C and PNW methods require an interest rate to be specified prior to analysis. That is, an analysis using a given interest rate will only be meaningful to another decision-maker with a similar opportunity cost. From a specific decision-making perspective, however, these criteria may provide more useful information than the IRR criterion. The B/C ratio determines the present value of net benefits per $1.00 of the present value of costs. PNW is merely the present value difference between benefits and costs; in effect, a measure of profit. In general, the case can be made that PNW should be the economic criterion used to select alternatives for investment when capital is limiting (Workman 1981, 1986).

Although these three economic criteria indicate economic feasibility of specific range improvements, none of them indicate an optimal intensity of project implementation. The economic principle of marginality provides the basis for finding the optimal level of input use for producing an output (Workman 1986). This principle indicates that the optimal sagebrush kill rate is the point where the marginal cost (MC) of obtaining one more unit of crested wheatgrass is equal to the marginal return (MR) to the ranch resulting from that unit of crested wheatgrass.

For a profit maximizer, the optimal level of crested wheatgrass production should be the management objective. Figure 2 shows, with hypothetical curves, how profit is maximized when MC equals MR.[1] As crested wheatgrass production increases from 500 to 1000 lb/ac, each additional pound of grass returns more to the ranch than it costs to produce. At 1000 lb/ac the point is reached where no further profit can be made. In fact, the next (and each succeeding) pound of crested wheatgrass actually decreases profit. The shape and position of the MC curve will be determined by the underlying production function and the relationship of input costs to percent sagebrush kill. The MR curve is assumed to be equal to the price per pound of crested wheatgrass. This value will vary from ranch to ranch depending on seasonal forage needs. In a ranching situation, this curve may be nonlinear (i.e. forage has a non-constant value).

The optimal kill rate will vary based on the relative values of inputs and outputs. As the output price increases relative to the cost of producing that output, the optimal kill rate will also increase (Workman 1986). That is, it will now be more profitable to invest more money in killing sagebrush since these marginal funds invested will be offset by the higher marginal revenue. Thus, the procedure needs to be used each time a decision is to be made. Although the production function would be expected to remain constant, results from a study conducted at a given point in time under a given relative price set will not necessarily be applicable in another situation.

DISCUSSION: THE PROPOSED OPTIMIZATION PROCEDURE

Based on the objective of profit maximization, the level of investment will be determined such that the maximum net returns (project benefits minus project costs) are realized. In the crested wheatgrass/big sagebrush model, the value of additional forage production will depend on the specific needs of a given ranch. These benefits must be maximized relative to the project costs (e.g. initial investment, annual costs, deferment costs). The purpose of this section is to: (1) outline the steps required to develop the proposed optimization procedure, (2) examine some relevant implications of different model formulations for making investment decisions, and (3) discuss data requirements for on-the-ground application of the model.

Steps in Development of the Model

The true value in developing an economic model lies in being able to apply it in a variety of situations. The procedure is merely an analytical framework for interpreting relevant data; a usable model will need to be developed for each ranch unit. Once developed, however, the procedure will provide useful information even if profit maximization is not the goal of the decision-maker. If another goal is relevant to the decision-maker, and a non-optimal kill rate is chosen, the model will indicate the trade-off involved. In general, model development should consist of estimating (1) a site specific production function, (2) project benefits, and (3) project costs. This order is based on the premise that if the biological relationship can not be estimated then the remainder of the model will not be useful. Next, estimation of project benefits requires the decision-maker to consider if, how, and when the additional forage will be used within the present operation. Finally, costs are estimated based on the least cost methods of attaining expected overstory kill rates. All information will be combined to determine the optimal intensity of overstory kill.

Overstory/Understory Production Functions.-The production function can be estimated in several ways. Percent kill of the overstory species can be estimated as either a deterministic or a stochastic value. The deterministic version is the percent kill based on the least cost improvement method for a given initial vegetation parameter (e.g. density, canopy cover, age structure). The stochastic version also includes random variables (e.g. precipitation, temperature). Forage production, also deterministic or stochastic, will then be a function of the estimated kill rate.

The shape of the production function can be estimated as linear, strictly concave, strictly convex, or sigmoidal. Results such as those shown in Figure 1 indicate that the production function will be strictly convex.

The time aspect of the overstory/understory relationship can be formulated either as a static or dynamic function. The static analysis uses an average production response as if it could be maintained over the life of the project (i.e. even flow). The dynamic analysis incorporates parameters that cause changes in understory production through time (e.g. rate of overstory re-establishment, grazing, fire). The dynamic aspect will not be directly addressed by this project except as it relates to the work being completed by Allen Torell (Torell and Godfrey 1986).

[1] See Doll and Orazem (1978), Chiang (1974), or Workman (1986).

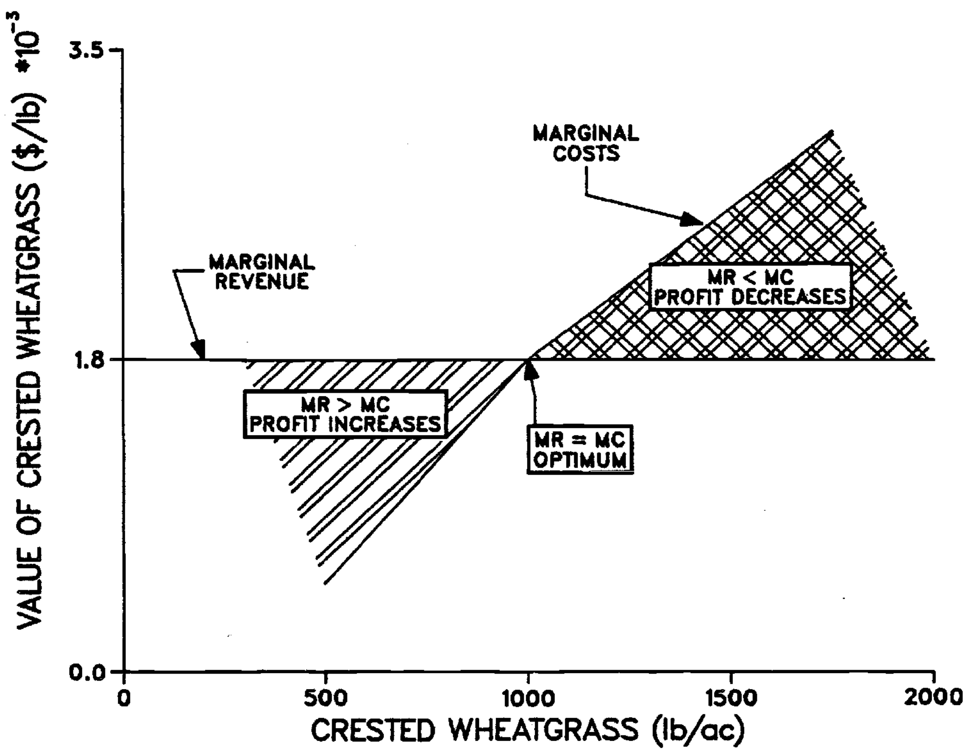

Figure 2.--Profit maximization occurs at the point where marginal revenue equals marginal cost as production output increases.

Estimated Project Benefits.--Project benefits to a specific ranch will vary among operations as well as for a given operation at different times. Additional crested wheatgrass production will only have value for a ranch if it balances seasonal forage production with seasonal forage requirements or replaces more expensive feeds (e.g. hay, grain) with less expensive forage.

Once it is determined that additional forage is needed, the value of that forage to the ranch can either be estimated as a constant value or as a value that changes with the level of production. In the former case, once it is shown that the forage can replace hay during winter, the value of an animal unit month (AUM) of forage may be assumed to be equal to the price of an AUM of hay. However, if more forage is produced than there is hay to replace, the extra amount will be valueless from a livestock production perspective unless other uses for the extra production of grass can be found. In the latter case, the marginal benefits from each additional unit of forage would likely decline from some relatively high value for the first forage unit down to zero value for the last useful unit of forage.

Total revenue derived from reduction of the overstory population will then be a function of estimated project values ($/unit) multiplied by the appropriate production response. The marginal revenue function can then be calculated from the total revenue function. As shown in Figure 2, the MR function is one piece of information required to find the optimal level of crested wheatgrass production.

Estimated Project Costs.--Project costs may be divided into initial investment, annual maintenance, deferment, and future stock costs. The model assumes that each range improvement alternative is applied in a technically efficient manner, and that this will result in an average overstory kill rate. In other words, some methods are better suited to flat topography on a large project than to rough topography on a small project.

For estimating initial investment, the cost of killing the overstory species is assumed to be a function of the selected method, initial density and age structure of the target population, project size, and other variables. Initial investment includes the cost of control in addition to any structural improvements (e.g. fences, water developments) needed to properly manage the site.

Because project benefits are calculated on a per year basis, it is necessary to convert the initial investment (a stock value) into an annual cost (a flow value) in order that the benefits and costs be comparable. The annual investment is determined through a procedure of amortization.[2] This process spreads the initial investment costs over the life of the project and adds the amount of interest payment necessary to compensate the investor for use of the capital.

2 The interested reader is referred to Workman (1986) or any textbook on finance.

The total annual cost can then be computed by adding estimated annual maintenance costs to the amortized initial investment cost. The total costs result in a cost equation (i.e. costs are expressed based on the amount of inputs used). However, to be comparable to the MR function estimated earlier, the total cost curve needs to be estimated using a cost function (i.e. one that relates costs to the production output). Once the cost function is estimated, the MC curve can be derived through the calculus. The MR and MC functions can then be equalized to find the production level where maximum profit occurs, assuming that the second order conditions for a maximum are satisfied.[3] This optimal production level can then be related to percent overstory kill required, relative to an optimal investment level.

Implications of Different Model Formulations

Determination of the optimal overstory kill rate by use of the theoretically correct model (equating marginal costs and marginal revenues) involves use of the calculus. The mathematical derivations make the method somewhat unwieldy from a management perspective. Nevertheless, it is important to understand how the theoretical model can be interpreted in terms of range improvement practices designed to reduce the specific overstory species to favor the desirable understory forage.

The principle of marginality determines the optimal level of production by finding the point where the slopes of the total revenue and total cost curves (as defined) are equal. Mathematically this is the same as finding the point where the first derivatives of each function are equal (i.e. MC = MR). Through mathematical manipulation of the MC and MR functions, the model can be reformulated into a more useful procedure. That is, a useful model should be relatively easy to manipulate in order to respond to changing economic conditions.

One modification of the MR equals MC procedure is a graphical procedure described by Workman (1986). This method involves plotting the production relationship between one input bundle and one output. If long-term carrying capacity of the site remains constant, this average production relationship will be useful for decision-making on a given site. However, if factors such as brush encroachment or stocking rate affect site productivity, this production relationship will be dynamic in nature and the decision criteria become more complex. For the simple model, assuming an average production function, there are implications for management based on how forage production, variable cost, and output price functions are estimated.

Once the production function is graphed it is a relatively easy procedure to find the optimal production level. The next step is to plot the ratio of input costs to output price as an iso-budget line. This line represents the combination of inputs and outputs that will exhaust a given budget. Conceptually, this assumes that both inputs and outputs are costs to the firm. Once the price ratio curve is estimated the object is to find the point where the price ratio curve becomes tangent to the production curve. This point is the optimum.

There are four cases of the one input and one output situation, each with its own implications for management. The four cases are displayed in Figures 3 and 4. A hypothesized linear production function (Fig. 3) will lead to recommendations different than a strictly convex production function (Fig. 4). By the same token, the linear and nonlinear price ratios each have different implications when combined with the appropriate production function form.

The first case is the linear production function-linear price ratio (Fig. 3a). As depicted, Price Ratio 1 indicates that the price of overstory kill is relatively high compared to the price of the forage. In this case, the management decision should be to not invest in this site. On the other hand, as the price of forage increases relative to the cost of control (Price Ratio 2), it becomes economically feasible to kill 100 percent of the overstory stand. With this model formulation, it is mathematically possible for the price ratio to lie exactly on top of the production function (i.e. it becomes tangent everywhere). In this case, the decision-maker should be indifferent as to the overstory kill rate.

The second case is a linear production function with a nonlinear price ratio (Fig. 3b). In this example the price of sagebrush control is expected to increase relative to the price of crested wheatgrass. This can be caused by a cost function that increases at an increasing rate, and because the value of the forage declines as more is produced. If either costs or benefits are assumed to be linear and the other one nonlinear as described above, the shape of the price ratio will be as shown in Figure 3b. The management implication is that the optimal kill rate will likely be somewhere between 0 and 100 percent. Thus, instead of an either/or situation, as depicted in the first case, the optimal kill rate can occur at any point along the production function, depending on relative prices.

The third case is a nonlinear production function with a linear price ratio (Fig. 4a). This example is similar to that depicted in Figure 3a except that the only possibilities are 0 or 100 percent kill. It would never be economically efficient to have a target kill rate other than at the end points.

The fourth case is a nonlinear production function with a nonlinear price ratio (Fig. 4b). This example probably represents the theoretically correct model and would be the most useful for making management decisions. In essence, the optimal control rate could occur at any point depending on the shape of the two curves. This model should provide the most realistic expected response.

Data Requirements for Model Application

As with any predictive model, the results are only as good as the data base. Three data sets, of equal importance, are required to drive this model. In the absence of an adequate data base, certain restrictive assumptions must be made. The data sets

[3] See Chiang (1974).

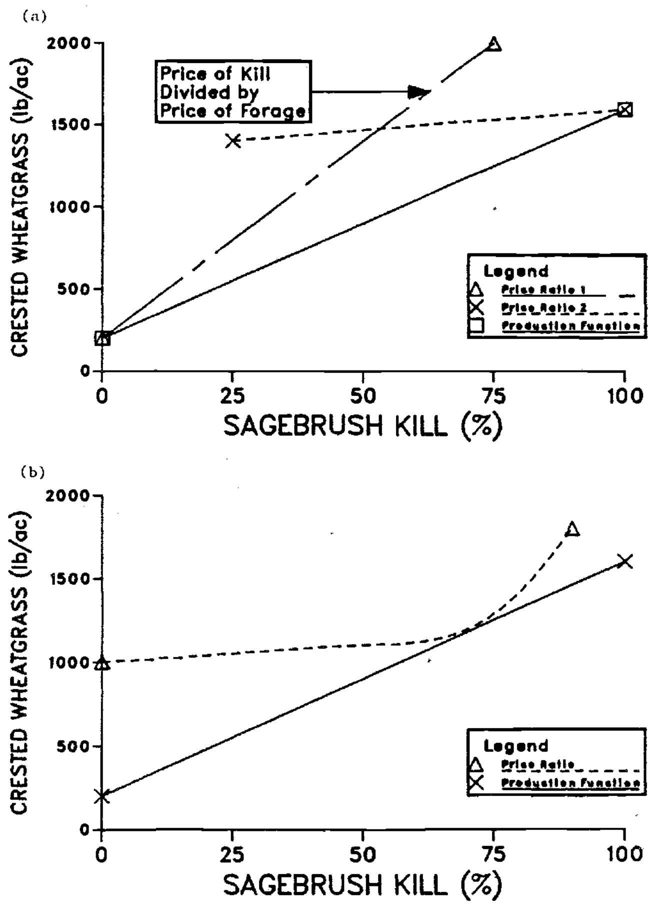

Figure 3.--Linear production function with linear (a) and nonlinear (b) cost functions.

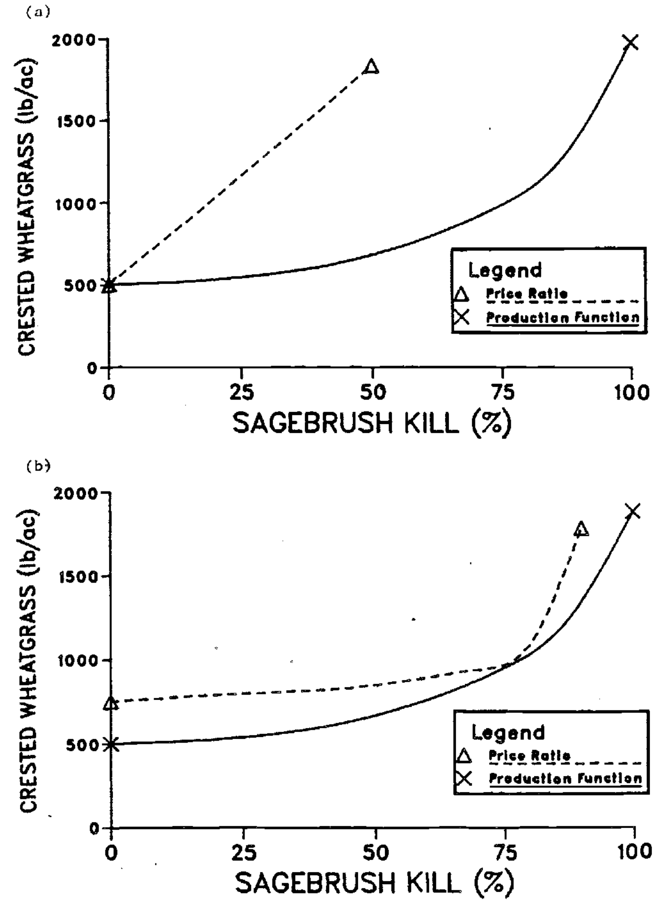

Figure 4.--Nonlinear production function with linear (a) and nonlinear (b) cost functions.

relate to the estimation of the production function, the input cost function, and the output revenue function.

Obviously, these three data sets are intricately interrelated. The greatest need for better data is related to the estimation of the production function. Ideally, the data set should be from a multi-rate experiment conducted for the life of the project. Impacts on forage production from the initial kill, as well as initial kill effects on overstory re-establishment, with and without grazing through time, are crucial factors in determining an optimum.

Range improvement research has primarily focused on determining whether or not there is a significant impact on understory production from control of the overstory population. These experiments typically involve up to five replications of sampling sites for the treatment and a control. It is possible to use the same number of samples (i.e. replications times treatments) and collect more useful information by rearranging the experimental design in order to provide data for function estimation. One such experimental design would be to have two replications and five treatment levels.

Input and output price data are relatively easy to obtain compared to the overstory/understory data. Input costs for a given range improvement should be tracked by physical units (e.g. labor, materials) rather than in total dollars spent. Further, these physical costs need to be related to initial stand parameters and post-treatment reponses if they are to be useful for estimating the cost function.

Output values will be the most variable because of differing specific needs of individual ranch operations. Based on these different values, economic feasibilty of the same range improvement practice will vary widely among operations. Therefore, even though the analysis may show a certain control rate to be the optimum for one ranch, extrapolations to other ranches must be made within the context of differences between operations. Thus, the need is for ranch-specific data both in terms of forage requirement and forage production/availability, on a seasonal basis, in order to determine the value to the ranch of additional forage in a given season.

CONCLUSION

The purpose of this project is to develop a usable analytical procedure to determine the economically optimal kill rate of an overstory species competing with desirable understory forage. Although the procedure is being developed within the crested wheatgrass/big sagebrush community, it should be widely applicable to other vegetation types.

An individual ranch unit is assumed to be the relevant decision-making unit. The investor is also assumed to be a profit maximizer for purposes of this analysis. In this framework, the procedure integrates biological relationships with costs and benefits of production, and the results are interpreted through range management principles. The final product should help in determining what is best from the ranch owner's perspective. It should also provide useful information to the public land manager by demonstrating the economic impacts of a range improvement decision on a public grazing allotment.

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