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METHODOLOGICAL ISSUES IN RANGE ECONOMICS: MODELING THE RANGE-LIVESTOCK PRODUCTION SYSTEM

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Introduction

Because of the size and diversity of the range resource, considerable research effort has been directed toward its management. Agricultural economists have addressed a variety of issues including allocation among competing uses, range resource valuation, estimation of fundamental production relationships, and evaluation of alternative management practices. However, despite the extent of the past and present range research agenda, economists have generally had less impact on range management practices and processes than in other areas, such as crop farm management. Many of the shortcoming of previous range economics research may be attributed to a lack of success in applying traditional research methodologies to the analysis of rangeland production systems.

At the root of range economist's past frustrations has been an inability to accurately represent the complexities that characterize the rangeland production system. Several features set rangeland apart from other production resources. Rangeland is by definition land not suited for more intensive uses; typically it is either too rocky, too shallow, or too dry for use in more intensive production systems. As a result of its extensive management, rangeland productivity is considerably less controllable than production in cultivated agricultural systems. The limited ability of the manager to manipulate the system is compounded by the temporal and spatial diversity of the range resource. Each management unit is characterized by a diverse set of plant species whose composition and productivity change both within as well as across production seasons. Also, because range productivity is driven primarily by ecological principles as opposed to cultural practices, long-term, multiple production period responses are more important than in cultivated agriculture.

These unique characteristics of the range resource interact to create a challenging set of problems for the applied researcher. First, range production is characterized by a greater interdependence of risk and dynamic response than crop production; failure to represent these influences can limit the empirical validity of range analyses. Also, in most cases range forage is an intermediate product. Intermediate product problems have always presented a challenge to economists, and in this case, the issue is complicated by the complex interactions involved in converting forage to livestock product. Finally, and perhaps most importantly, the same factors that make rangeland unique also make it difficult and expensive to obtain adequate information to conduct empirical analyses. This lack of adequate response data has contributed more to range economists' past frustrations than any other factor.

It is beyond the scope of a single paper to address the complete set of methodological issues involved in range-related research. This paper will focus on the "ranch management" side of range economics, leaving the discussion of public resource management issues to the remaining papers of the session. Research in this area has been primarily directed toward long-term (inter-seasonal) management of the range resource. Undoubtedly, the issue receiving the most attention has been the economic evaluation of range resource improvements (e.g., chemical and mechanical brush control). Other important inter-seasonal management decisions include selection of breeding herd replacement (culling) practices, allocation of rangeland among competing uses, and adoption of grazing systems. Within this long-run decision environment lie several intra-seasonal decisions related to the efficient utilization of range forage produced through the year. Important controls involved in intra-seasonal management include decisions concerning enterprise selection, stocking rate, grazing duration, and supplementation. These decisions also have long-run implications since improper range utilization can affect the future productivity of the range site.

Range economists have applied numerous research methodologies in an attempt to address these issues. This paper seeks to summarize methodological advancements of significance to range economics and evaluate their contribution to the improved understanding and representation of the range-livestock production system. Do these advancements offer greater potential for improved specification of rangeland production, or

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alternatively, are we still faced with the same data limitations and ignorance of the underlying production relationships that plagued earlier research efforts?

This discussion will concentrate on four methodological approaches of significance to past and present range research efforts: (1) operations research techniques, (2) biophysical simulation models, (3) dynamic optimization models, and (4) knowledge-based or expert systems. Attention will be focused on the potential of each approach in representing the unique characteristics of rangeland production in addressing the decision problems identified above.

Operations Research

Operations research is a general term applied to any approach to, or methodology used for, decision making which incorporates specific outcome objectives and information about controllable and uncontrollable factors which may impact the outcomes in a quantitative model of the decision process (Richmond). One of the oldest and most commonly used operations research techniques is mathematical programming. Specifically, linear programming (LP) has been used extensively in agriculture since World War II. Extensions of linear programming used in agricultural decision analysis include dynamic LP (also called multiple period or serial LP), recursive LP, and risk programming. Simulation models represent another important operations research technique and may be defined as quantitative models of sequential, stochastic and interactive aspects of decision processes which illustrate the impact on an outcome of specified levels and combinations of controllable and uncontrollable factors.

Mathematical Programming

In one of the first documented discussions of the use of linear programming in range economics research, McCorkel indicated two general problem areas where LP could be beneficial: (1) evaluating the feasibility of range resource improvements, and (2) selecting among alternative uses of rangeland. He also noted that problems of adequate data on outputs (production response), temporal relationships and resource heterogeneity limited the effectiveness of LP in solving range-related problems.

Since McCorkel's paper, several studies have used LP to address both types of problems. Relatively fewer applications of LP to problems related to range improvement decisions have been undertaken. Among the first examples were studies by Barr and Plaxico and Sharp and Boykin. These studies used multiple-period LP models as a means of dealing with the dynamic production response characteristic of range improvement practices. Multiple period (serial) LP models have since been used by several others, both in problems related to range improvement (Freeman et al. and VanTassell and Conner) and resource allocation (Bartlett et al.). Recursive linear programming models, where resource constraints were updated based upon range investment decisions in previous periods, were also proposed as a means of more realistically modeling production response to range improvements (Spielman and Shane). However, the practical usefulness of these models as well as multi-period LP in analyzing range improvement investments has been greatly limited by their deterministic structure, simplistic representation of forage dynamics, and cumbersome size.

During the last three decades, LP has been used in a variety of research efforts directed at intra-seasonal management decisions (optimal use of rangeland, optimal enterprise mix), eg., Nielsen et al., Navon, D'Aquino, and Woodworth. A principal limitation of these studies, as well as the range improvement analyses referenced above, was their inability to accurately represent the complexities that characterize range-livestock interactions. Most studies employed a simple forage balance procedure to allocate available forage among alternative livestock enterprises. However, such a static approach does not represent the dynamic relationships between forage availability, forage quality, intake, and livestock performance. Such relationships are far from linear and simply cannot be specified accurately within the rigid structure of linear programming models. A more recent non-linear programming formulation of nutrient requirements and feed intake for cattle proposed by Apland does address some of these concerns.

The deterministic aspects inherent to the LP procedure have also limited the empirical validity of the above approaches. Quadratic (risk) programming was initially used as a means of incorporating variance of income into the optimization process in analysis of range related problems in the 1970's (Whitson et al.). Later, Minimization of Total Absolute Deviations (MOTAD) LP models were utilized to evaluate expected profit-risk trade-offs in livestock and forage enterprise selection problems (Gebremeskel and Shumway, Glover and Conner). While quadratic programming and/or MOTAD techniques offer a means of incorporating risk and multiple time periods into the optimization process, their application to range related decisions has been limited by lack of sufficient data to adequately estimate variance. Livestock producers face uncertainties in the quantity, quality and timing of forage production, as well as converting this production to final output. Thus, quantification of production risk is considerably more complex than in crop applications. Also, the commingling of different sources of variation, i.e., production levels and prices (costs), can lead to significant problems in interpreting results.

Firm Simulation

In a 1964 address to the AAEA, Suttor and Crom listed several advantages and disadvantages of simulation. Among the advantages were a) simulation models can be much more complex and realistic than conventional (programming) models, b) simulation allows incorporation of qualitative aspects of human decision making, and c) simulation facilitates aggregation of representative firms, households, etc. Disadvantages listed included a) simulation models tend to be complex, making it difficult to explain all built-in assumptions, b) models tend to be problem (situation) specific which may result in a proliferation of models, and c) costs of computing, data collection and estimation will likely be high. Probable uses of simulation in applied agricultural economics research identified in the address included policy analysis, studies of alternative decision rules for firm managers, and regional and multi-sector analysis. In the area of range economics, most applications have focused on evaluating the affects of applying alternative management strategies over a multiple-year time horizon.

The first and best known use of simulation analysis of a rangeland-livestock production system was conducted by Halter and Dean. They modeled the decision process of a large California ranch-feedlot to assess alternative decision rules related to buying stocker and feeder cattle and the transfer of cattle from rangeland to feedlot. The model allowed for the simultaneous variation of range condition (forage production) and stocker, feeder and fat cattle prices. They concluded that simulation was a promising tool for problems where uncertainty characterized the decision making environment and a large number of time-related interrelationships existed among variables.

Despite the recommendation of Halter and Dean there were few, if any, other applications of whole-firm simulation models to problems related to the range-livestock industry until the 1980's. This dearth is surprising in light of the uses of simulation in other areas of agricultural economics, eg., Patrick and Eisgruber and Hutton and Hinman.

In 1982, Beck et al. reported the use of simulation to assess the risks and returns to an Australian cow-calf producer from improving pasture by re-seeding and fertilizing. The model incorporated functional relationships between stocking rates, climatic conditions and calf productions. Cattle prices and climatic conditions were stochastic variables in the model.

In 1986, a simulation model of a Texas cow-calf operation was used to assess the economic consequences of alternative stocking rate adjustment decision rules (Riechers et al.). The model included climatic conditions and cattle prices as stochastic variables and included functional relationships among climatic conditions, forage production, beef production and feeding costs. VanTassell recently adapted the Firm Level Income and

Policy Simulator (FLIPSIM) (Richardson and Nixon) to represent range-livestock production systems. The modified FLIPSIM was used to evaluate the impacts of implementing alternative range improvement practices and grazing systems on firm success and survivability. Another recently developed simulation model was used to assess economic impacts of range improvements on a stocker cattle enterprise (Bernardo et al.).

Firm simulation has generally proven to be less useful in range-related research than originally anticipated. In crop production agriculture, simulation has been very useful in evaluating impacts of policy (program) alternatives on production acreage, income distribution, etc. However, in range-livestock production no general production and/or marketing control policies exist. The use of simulation in the analysis of range-livestock production has also been hindered by a lack of sufficient forage and livestock production response data to estimate probability distributions. This problem is exacerbated by the complexity of the range forage-livestock production relationship. Even where sufficient data are available to estimate variability in forage production and forage quality, difficulties are encountered in translating this information into estimates of variability in livestock performance (eg., weight gain, weaning percent, etc.). Range economists have been forced to incorporate rather simplistic biological models in firm simulators to represent these interactions. Significant future use of firm simulation models in the range-livestock area will likely depend on the availability and adaptability of more process oriented biophysical simulation models

Biophysical Simulation

Interest and use of biophysical simulation in agricultural research has increased significantly over the past two decades and continues to accelerate. For our purposes, biophysical simulation models will be defined as computerized models that focus on and characterize the interaction of weather, soil, and biological and/or physical processes in agricultural production. To some degree, biophysical simulation has been shunned by agricultural economists because of its non-optimizing nature and employment of non-statistically based parameters. More recently, agricultural economists have recognized the descriptive value of these models in representing physical processes in the analysis of agricultural production systems.

Despite the proliferation of applications in the analysis of crop production, considerably fewer applications of biophysical models have occurred in the area of livestock management, particularly with respect to rangeland production. Two factors that have impeded the application of biophysical models to rangeland decision making are the limited focus of current biophysical range models and problems associated with applying these models in normative economic analysis.

One of the most perplexing problems in the development and use of biophysical models centers around the scale of their focus. Some models focus on a specific crop or animal component (e.g., the animal rumen or a single plant) with little attention given to how these results can be aggregated to an economic unit. The result is a model well-suited for explaining a particular biological process, but too myopic and data intensive for economic application. This problem is particularly acute in rangeland applications because of the large data requirements necessary to describe complex range-livestock production systems. Most models of crop and tame pasture systems have focused on a single plant and assumed a homogeneous plant population to aggregate results to field level. Given the heterogeneity that characterizes the range resource, such an approach is not possible, thus increasing the data requirements of biophysical range models. The difficulties and expense of collecting rangeland data exacerbates this problem making transfer of models to new locations and the necessary validation extremely difficult and time consuming.

Another factor limiting application of biophysical models in range economics research has been the independence of modeling efforts by animal and range scientists. A long-held objective of animal scientists has been the prediction of animal performance given a fixed feed resource. Developers of biophysical livestock models have often taken a similar tact, developing formulations to simulate production under specified assumptions of feed quantity and quality. Sanders and Cartwright, Brorsen et al., and Fox and Black are all examples of cattle simulation models employing this 'fix one - predict one' approach. While useful in the controlled environment of a feedlot, such models ignore a number of the fundamental plant-animal interactions comprising the range-livestock production system. Since the quantity and quality of available forage does not respond to consumption by livestock, the models cannot adequately represent the consequences of management adjustments of interest to range economists (eg., variation in stocking rate, types of livestock, etc.). A separate line of biophysical models designed to simulate the growth and development of range plants has also evolved. These models ignore livestock production, and thus, are of limited use to production economists evaluating the effects of management adjustments on economic output.

The future of biophysical simulation in range economics research greatly depends upon the fusion of these two lines of research. A small number of models integrating range and livestock components have been developed; however, their extreme complexity and large data requirements have prevented economic application. Range economists must taken an active role in multi-disciplinary research efforts aimed at constructing more management-oriented simulation models. Obviously, such an effort will require a considerable time investment on the part of individual scientists; however, the potential gains from such a commitment are significant.

An additional problem, common to all economic applications of biophysical models, concerns how they may be incorporated into decision analysis. To date, there exists no well-defined, generally accepted theory around the use of such models, as is available with production functions and neoclassical theory. Since the calculus of maximization no longer provides a workable means of finding a solution, the researcher is left without many traditional methods of analysis. Two general approaches have been used by economists in applying biophysical models in empirical analyses.

One approach involves simulating alternatives in a non-optimizing framework to evaluate the economic consequences of various management practices under alternative environmental conditions. Such an approach supports Musser and Tew's contention that "simulation does not propose to identify optimal plans for managers; rather it proposes to provide information which most likely has qualitative value for managers." While such a positive approach may sometimes by viewed as ad hoc and/or unscientific by some, its contribution to the range economics discipline should not be overlooked. Simulation provides a large step forward in understanding the dynamic processes of rangeland production and provides an opportunity for more meaningful treatment of risk in ranch decision analysis. Biophysical models hold the potential to provide response information, the lack of which has severely constrained our ability to conduct meaningful decision analysis for ranchers.

Some degree of normativism can be introduced into these analyses by simulating a variety of strategies and applying some economic criteria to rank the outcomes. This criteria may be deterministic (eg., profit maximization) or stochastic (eg., stochastic dominance and generalized stochastic dominance). Such an approach is common in crop applications where biophysical models have been run for series of alternative strategies and the resulting net return distributions ranked using stochastic dominance techniques. Similar applications in the area of livestock management are less prevalent, although evaluation of grazing systems on improved pasture has been conducted using these procedures (e.g., Parsh and Loewer).

An alternative approach offering considerable promise in incorporating biophysical simulation in production economics research involves the direct optimization of biophysical models. Such an approach requires the coupling of the biophysical model with some form of search algorithm or control theory technique to explicitly represent the sequential characteristics of the decision problem. Trapp and Walker envisioned the development of a

"New Theory of Production Economics" when biophysical simulation models and dynamic optimization theory were properly wedded. This alternative approach is addressed in the following section.

Dynamic Optimization Models

As discussed earlier, many of the unique features of rangeland production interact to form a truly dynamic system. Range researchers recognized the importance of dynamics in representing range-livestock production and sought alternatives to traditional static approaches. The decisions facing rangeland managers can be conceptualized within a framework proposed by Antle which describes the production model as a sequence of "stage production functions" whose output feeds forward as input for the following production stages. Multiperiod dynamic decision problems may be differentiated from single period problems by three characteristics: (1) sequential dependence of decisions, (2) information feedback between production periods, and (3) revision of previous decisions as new information becomes available. This information, ignored in most approaches discussed thus far, plays a major role in both the inter- and intra-seasonal decisions facing range managers.

In the December, 1982 issue of the *Western Journal of Agricultural Economics*, the proceedings of an invited paper session discussing the relative merits of dynamic programming and optimal control theory are presented (Burt, Zilberman, Talpaz, Howitt). It is interesting to read this discussion in light of developments that have occurred in dynamic analysis since that time. Although differing in their reasoning, all of the authors conceded numerical solution of empirical applications of optimal control theory to be a rarity at the time. Burt argued that the discrete characteristics of dynamic programming make it more realistic in agricultural applications, as well as more operational. In espousing the merits of control theory, Talpaz stated that applied solutions of control theory models may become increasingly feasible as advances in non-linear optimization algorithms are made. Applications of dynamic optimization methods to range management decision making have followed these insights. Most range applications to date have employed dynamic programing; however, limited use of control theory has occurred and additional applications appear eminent. Important empirical contributions have been made in the application of dynamic optimization models to both inter-year as well as intra-year decision problems in range management.

Most early applications of dynamic optimization methods in range economics focused on intra-seasonal decision making, specifically, optimal timing of long-term range improvements. In 1971, Burt published the first application of dynamic programming to the range investment problem. In an earlier study, Cotner had characterized the problem of determining the optimal timing of range improvements as an extension of the classic replacement problem. Burt formulated the problem in a dynamic programming framework and applied the model to the analysis of pinyon-juniper control. This paper provided the impetus for some lively debate concerning the appropriateness of applying dynamic models to the analysis of complex biological phenomena, such as forage response to range improvements. In response to the article, Martin stated: "The overwhelming lack of response data has produced an evolutionary change (of rangeland economics) to complete mathematical purity." Burt (1972) rebutted these conclusions by stating that lack of data is insufficient reason to write-off range research as futile; logical correctness in economic analysis requires that dynamic problems be analyzed as such.

This dialogue is illustrative of a fundamental controversy concerning the application of dynamic optimization models in range research. Now, nearly two decades later, can we make any more conclusive statements concerning our ability to represent dynamic phenomena in range investment analyses? A brief review of some more recent applications of dynamic programming to the range investment problem may shed some light on this situation.

Important issues not considered in Burt's seminal work were the interaction of grazing and brush encroachment and the influence of uncertainty on range improvement decisions. More recent research has addressed these issues. For example, Torrel used dynamic programming to determine optimal stocking rates and retreatment schedules for crested wheatgrass stands. Results indicated grazing intensity did affect the rate of sagebrush encroachment and should be considered in timing range improvements. Karp and Pope used stochastic dynamic programming to simultaneously determine stocking rates and the frequency of brush control investments. Stochastic properties of range response were incorporated into the decision framework via finite Markov chains. By the authors' own admission, specification of the transition probability matrices was based upon sparse data, thus limiting the generality of the optimal control rules derived. In a more recent treatment, Bernardo used stochastic dynamic programming to determine the optimal frequency of chemical treatments and prescribed burns, as well as accompanying stocking rates. In a revised version of the model, a range site simulation model was used to estimate the required transition probability matrices. Such an approach offers promise for improving the stochastic specification of inter-seasonal forage dynamics.

One application of optimal control theory to inter-year decision making is Standiford and Howitt's recent treatment of multiple-use management of California's hardwood rangelands. Equations of motion for oak density, forage production, and livestock density as well as several production functions were estimated based upon several empirical studies. The discrete optimal control model was solved using non-linear optimization techniques to evaluate optimal management for firewood production, livestock production, and commercial hunting. This initial phase of the research was deterministic; however, a stochastic adaptation of the model is forthcoming.

Over the past several years, considerable development in the empirical sophistication of dynamic range investment models has occurred; however, range economists still struggle to specify the production relationships underlying these models. During this time, little has been achieved in increasing the availability of experimental data reporting vegetative and/or livestock response to range improvement. Given the high cost of range improvement experiments and the limited transferability of their findings, future prospects for obtaining these data also appear limited. Biophysical simulation provides some potential for overcoming this problem; range economists may need to adopt a more mechanistic (non-statistical) approach in deriving relationships describing vegetative response through time. Despite difficulties in validating empirical results from dynamic range investment models, range economists have gained much from such efforts. In addition to providing insights into rangeland dynamics not available from static models, past dynamic programming applications have been useful in identifying important data necessary for economic evaluation of range improvements.

Perhaps a more interesting problem in economic dynamics is that of intra-seasonal management of rangeland production systems. A recent application of dynamic programming to intra-seasonal decision making is that of Rodriguez and Taylor. These authors developed a stochastic dynamic programming model to evaluate supplemental feeding and marketing strategies for the production of yearling cattle on rangeland. Three state variables -- forage standing crop, livestock weight and livestock density -- were used to describe the production system. Forage dynamics were represented by first estimating forage production in each two-week subperiod as a function of stochastic rainfall, then determining standing crop as a function of subperiod production and livestock intake. This research provides direction for future dynamic programming applications in this area. To maintain computational tractability, a relatively simple representation of forage dynamics was employed. More complete descriptions of forage response and the range-livestock interface will almost certainly be the focus of future intra-seasonal range management models.

Recently, several applications of optimal control theory to the analysis of livestock production systems have been conducted. For example, Chavas et al. developed and applied a differential equation specification of a biological growth model for swine to derive optimal input use and replacement policies. Trapp used a gradient search technique to analyze the cow replacement problem and tied the method to control theory in a subsequent comment. Hertzler employed a six equation continuous model of animal growth to analyze optimal feeding strategies in feedlot management. This research indicates that the profession is achieving an enhanced ability to consider larger, more complex, and hopefully, more realistic, representations of dynamic production systems in optimal control models. While none of these applications address the question of intra-seasonal allocation of range resources, they do provide direction for future applications in the range area. Such studies appear to be examples of what Trapp and Walker were envisioning in their "New Theory of Production Economics." In actuality, these works do not represent a "new theory", but rather a more complete representation of underlying production relationships in dynamic optimization models.

Knowledge-Based (Expert) Systems

Expert systems are one of several subdisciplines or branches of artificial intelligence. Other subdisciplines include theorem proving, game playing, machine learning, pattern recognition, natural language processing, robotics and machine cognition (Barrett et al.). Expert systems are designed to diagnose and solve problems based on soft data or heuristics through construction of intelligent knowledge bases elicited from domain experts in the problem area (Harmon and King). Although they work best on narrowly focused problems with a well structured knowledge domain, expert systems are useful in overcoming the qualitative deficiencies of reductionist problem investigation and prediction methodology. Capabilities of expert systems include analysis, symbolic logic, diagnosis, design and decision support. For a complete guide to the design, development and use of expert systems see Waterman or Harmon and King.

Blank and Gum indicate that by their very nature, expert systems will play a larger role in education than in research. Although they are designed for problem solving, they will be of limited research use because the logic and methodology for solving the problem must be developed before the expert system can be built (Garson). In short, expert systems provide a powerful way to transfer problem solving knowledge to non-experts. Given the shortcomings of past range economics research in this area, a brief discussion of possible applications of expert systems in the range area is given.

According to Barret et al., uses of expert systems in agriculture will likely be in two primary areas; decision support and troubleshooting (diagnostics). Specific areas of application proposed include resource, financial, pest and personnel management; marketing support and program evaluation. Whittaker et al. offer a more detailed list of potential uses for expert systems in agriculture which also includes resource conservation, animal production management, and enterprise mix and expansion planning.

Expert systems may fill a decision support role as either the primary (or only) technique applied to analysis of a problem or as a secondary or supportive technique within a larger decision support system. Starfield and Bleloch contend that the context of a (simulation or optimization) model; i.e., what it addresses, what is assumes, when it should be used (what situation) and the interpretation of its output; are important details which are usually slighted in most analytical reports. They suggest that context details are slighted because details of the model can be presented within a conventional algorithmic structure while no formal structure exists for addressing questions of context. They propose the use of expert systems as "front-ends" or "back-ends" to the conventional models; the former to insure their proper use, and the latter to enhance interpretation of output. An alternative approach would be to include imbedded expert systems as components of larger models that could be used to solve specific subproblems within a decision support system.

To date, relatively few expert systems related to problems associated with range-livestock systems are available, although some applications in this area are reportedly under development (McGrann and Fredricks). One example of those reported to date which relates to range-livestock production is an expert system developed by McGrann and Powell to facilitate evaluation of a farm or ranch's financial condition. Another example, more directly related to range management, is provided by Ekblad et al. This system was developed to assist range management specialists in assessing a ranch manager's ability to implement specific range improvement practices and achieve the levels of economic returns predicted from technical production response data and capital budgeting. This expert system functions as a "back end" on a large decision support system designed to assist ranchers in strategic planning involving investment analysis of alternative range improvement and grazing management practices. The system solicits information on the managerial environment, past experience and other aspects to rate the manager's chances of success.

While these two examples are not indicative of the spectrum of range-livestock problems for which expert systems are being, or will soon be, addressed, they are indicative of some characteristics which will undoubtedly be evident in most expert systems related to range economics. First, they are targeted to assist ranchers or service agency/industry personnel as opposed to researchers. This targeting is consistent with the predominance of the knowledge transfer role of expert systems mentioned earlier and may foretell an era in which economists will be better able to positively impact range management practices and processes. Second, the two examples illustrate the positive role that expert systems can play in the integration and enhancement of other traditional analytical and/or diagnostic methodologies used by economists. With the aid of expert systems as "front-ends" and "back-ends", many of the problems encountered in applying traditional operations research models to range management decision making could be alleviated. Finally, expert systems offer a structured means of obtaining and using "expert knowledge" of technical production response in situations where hard data or simulated data are not available. In the Ekblad model, the expert knowledge was solicited only from "management experts"; however, similar processes could be used to obtain and imbed knowledge from brush management experts, range wildlife specialists, etc. Such a function could be particularly important in range applications, given the problems data limitations have presented in the past.

Conclusions

Range economists have continually struggled with representing the range-livestock production system in economic models, thus limiting their influence on both public and private range policies and decisions. Several unique characteristics of the range resource interact to form a complex decision making environment, much of which has not been adequately addressed using traditional modeling approaches. Economists have been further frustrated by a lack of experimental data reporting livestock and/or forage response to management practices and environmental influences. In light of these problems, economists are faced with three alternatives: (1) declare range economics research as futile, (2) continue efforts to apply traditional, static operations research methods in range analyses, or (3) attempt to model the system as what it truly is -- a dynamic, sequential production process.

Obviously, we favor the latter alternative. The first alternative is clearly unacceptable, while alternative two may be discounted by the fact that little progress has been made over the last three decades in overcoming the data limitations referenced earlier. Clearly, a change of approach is in order, and in actuality, such an evolution has been gradually occurring for several years. Range economists must adopt a more process-oriented approach to representing the range-livestock production system. The dearth of production data encountered by range economists does not imply a lack of knowledge of the underlying production processes, but rather an inavailability of data that can be fit into the narrow confines of traditional research methods. By focusing their attention on production processes, rather than more aggregated static response models, range economists should be able to establish better lines of communication with range and animal scientists.

Recent advancements in the areas of biophysical simulation, dynamic optimization, and expert systems offer significant opportunities for improving the empirical validity of range analyses. Application of biophysical models should prove particularly beneficial in understanding production processes underlying intra-seasonal management decisions. Improved solution techniques and greater understanding of dynamic production processes should increase the number and quality of dynamic optimization applications to inter- and intra-seasonal management issues. Both methods are process oriented and are more compatible with the research approach and findings of range scientists. Finally, advances in expert systems offer new opportunities for transferring research findings to range managers.

It is recognized that these approaches are not a panacea for all of range economists' past ills. Application of these techniques requires an increased commitment on the part of range economists to better understand the underlying processes of the range production system. In addition, such an approach is not without data needs; in fact, research methods such as biophysical simulation and dynamic optimization are probably more data intensive than traditional methods. The difference lies in the compatibility of these data with what is available from the range science profession.

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