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GRAZING MANAGEMENT: TECHNOLOGY FOR SUSTAINING RANGELAND ECOSYSTEMS?

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Abstract

This paper examines the ecological, economic, and social aspects of grazing management technology as it relates to sustaining rangeland ecosystems. We adopt FAO's definition of sustainable agriculture, that is, "The management and conservation of the resource base and the orientation of technological and institutional changes in such a manner as to insure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development is environmentally non-degrading, technically appropriate, economically viable and socially acceptable."

We explore the ecological aspects of grazing management as they relate to the need to balance solar energy capture and harvest efficiency so as to maximize productivity on a sustained basis. The long-term success or failure of all grazing strategies hinges around management's ability to control the frequency and severity of defoliation of individual plants over time and space. This is a particularly formidable challenge in rangeland environments because of high levels of environmental uncertainty.

We then focus attention on the social aspects of grazing management. Grazing management is a social process by virtue of its human component and the major social dilemma encountered in grazed agroecosystems centers around the impacts that ever-increasing human desires have on rangeland resources. We examine the role of ecological economics and the impact of varying human value systems on management of rangeland resources. The fundamental problem encountered in the management of natural resources such as rangeland ecosystems is absence of perfect ecological knowledge.

We conclude that the major social dilemma of grazing management stems largely from two phenomena: 1) supply side management tactics designed to meet ever increasing human demands; and 2) potential failure to accurately factor long-term ecological costs into present day value systems. As such, we conclude that current grazing management technology necessarily requires moderate rates of stocking be employed to insure rangeland agriculture (i.e. grazing) is ecologically sound, economically viable, and socially acceptable.

Introduction

When originally asked to write this introductory paper for this special issue of *The Rangeland Journal*, we were excited and pleased. However, the pleasure was short-lived as we struggled to identify a broad-based theme that would make a meaningful contribution amongst a series of sharply focused papers. In this struggle, we battered about a wide array of topics. But, in the end we chose the theme of sustainability because: 1) projected increases in human population with its concurrent increasing demands on agriculture necessitate agricultural lands be managed in an ecologically appropriate and fully sustainable manner; and 2) grazing of indigenous rangelands is one of the most sustainable forms of land use known.

Our approach will be to first define sustainability as it relates to agriculture in general, and specifically rangeland agriculture (i.e. grazing). We will then review the merits and potential shortcomings of current grazing management technology as it relates to both ecological and sociological sustainability. We will then present our vision of 21st century management technology that will be used to sustain rangeland resources.

It is important readers understand that our repeated use of data sets from the Texas Experimental Ranch is born out of our familiarity with the data rather than a belief that the data is somehow unique. Much to the contrary, we use the data simply because: 1) our grazing management paradigms are intimately tied to these data; and 2) we are confident they accurately reflect the fundamental workings of the key ecological processes associated with the management of rangeland agriculture.

The challenge

"Grazing management is the process whereby grazing and browsing animals are manipulated so as to accomplish a desired result" (Society for Range Management 1989). Although this and similar such definitions are readily accepted by many, "desired results" may range from single goals, such as production of livestock products or picturesque aesthetics, to multi-use goals such as acceptable levels of livestock production coupled with maintaining quality wildlife habitat and ample recreational space. But regardless of short- and intermediate-term goals, the ultimate "desired result" centers on sustained use of the rangeland resource. The challenge to the grazier is, as Aldo Leopold wrote many years ago, "to live on a piece of land without spoiling it" (Leopold 1938).

The concept of sustainability in agriculture is a subject of vital interest to many segments of the world's society. However, it is also a subject of lively debate which stems largely from differing viewpoints as to what constitutes a sustainable agriculture practice (USDA 1980, Douglas 1985, Lowrance *et al.* 1986, Dover and Talbot 1987, Keeney 1989, Pearce *et al.* 1989, Commonwealth of Australia 1991, Crews *et al.*. 1991, Standing Committee on Agriculture 1991, Science Council of Canada 1992, Lehman *et al.*. 1993, MacLeod and Taylor 1994, Walker *et al.* 1994). As such, no concise, universally acceptable definition of sustainable agriculture has yet emerged. This is in part because sustainable agriculture is often viewed more as a management philosophy rather than a method of operation (MacRae *et al.* 1993) and as such, acceptance or rejection of most definitions is linked closely to human value systems (Clark and Weise 1993). Still, it can be reasoned from a very conservative viewpoint that fully sustainable agriculture is agriculture that can be practiced forever (i.e. eternity). It is those agricultural practices that can continue without interruption regardless as to whether ample quantities of stored solar energy (e.g. fossil fuels) are available. It is from this perspective that we suggest grazing is one of the more sustainable forms of agriculture. It is 'natural agriculture' and without doubt the most ancient form of agriculture known.

But regardless of precise definition, most would agree from a utilitarian point of view that sustainable agriculture practices must be ecologically and economically sound as well as socially acceptable. Thus, we believe the definition of sustainable agriculture forwarded by the Food and Agricultural Organization (1991) is quite acceptable for the purposes of this paper, that being "The management and conservation of the resource base and the orientation of technological and institutional changes in such a manner as to insure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development is environmentally non-degrading, technically appropriate, economically viable and socially acceptable."

The challenge facing agriculturalists today is the need to increase productivity so as to provide adequate amounts of food and fibre to feed and clothe an ever expanding human population in a manner that is fully sustainable. In meeting this challenge we recognize sustainability is most likely impossible if human populations continue to expand indefinitely. We also recognize that at least for the short term (10-50 years), human populations will continue to expand rapidly (e.g. see Brown *et al.* 1995). Moreover, we recognize that just as the phenomenal growth of the world's human population has been fueled historically by agriculture, so will future generations. As such, the challenge to rangeland agriculturalists is: How do we manipulate grazing and browsing animals so as to maintain the ecological integrity of rangeland ecosystems while simultaneously garnering an economic profit with the full approval of society (e.g. see Walker 1993, Nores and Vera 1993, Huntsinger and Hopkinson 1996)?

Grazing management and ecological sustainability

Grazing as an ecological process

Grazing is the process whereby animals consume plants to acquire energy and nutrients to be used for growth and maintenance. It is an ecological process in that the energy captured and stored by primary producers (i.e. green plants) is consumed by primary consumers (i.e. herbivores). Grazing is also an agricultural process in that the grazers themselves and their byproducts are often utilized by humans as either foodstuff or items of comfort. Thus, it can be reasoned that grazing is a form of animal agriculture and the primary form of rangeland agriculture.

Ecological challenges

The major biophysical challenge in grazing management centres around the necessity to balance solar energy capture and harvest efficiencies so as to maximize productivity on a sustained basis. This ecological dilemma (Briske and Heitschmidt 1991) has been eloquently demonstrated in a classical experiment by Parsons *et al.* (1983) designed to quantify the effect of two grazing intensities on energy flow in a seeded pasture environment. Results (Fig. 1) showed when herbage consumption was low, primary production increased. For example, it was found that although herbage consumption was about 40% less in the leniently than severely grazed pasture, total amount of solar energy captured was about 43% greater. As a result, estimated harvest efficiencies (i.e. proportion of captured solar energy consumed by targeted herbivore) were about 13% and 25% in the leniently and severely grazed pastures, respectively.

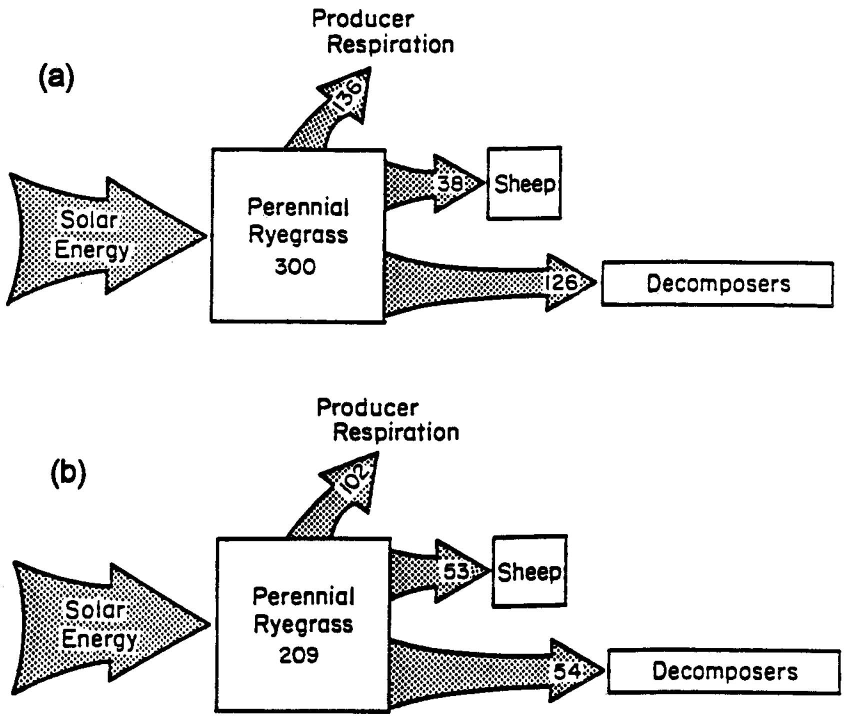

Fig. 1. Energy flow (kg carbon/ha/day) in (a) leniently and (b) severely grazed perennial ryegrass pastures (from Briske and Heitschmidt 1991, after Parsons *et al.* 1983). Results demonstrate fundamental ecological dilemma encountered in grazed ecosystems, that being our inability to concurrently maximize efficiency of solar energy capture and harvest efficiency.

This challenge is particularly formidable in rangeland environments because of several inherent constraints. The first constraint is that primary productivity is inherently low because rangeland environments seldom provide an optimum plant growth environment. The most common constraints are limited water and nutrient supplies, excessive temperatures, and unfavorable topography. As a result, rangeland forage densities are low thereby dictating low animal densities. Thus, management of rangelands is often described as extensive in that grazing strategies focus on the use of relatively large areas of land per animal and relatively low levels of labor and capital (Forage and Grazing Terminology Committee 1991).

The second constraint challenging management's ability to optimize solar energy capture and harvest efficiencies is temporal and spatial variation in climatic conditions (Friedel *et al.* 1990, Stafford Smith and Morton 1990). For example, seasonal and annual droughts are common in most rangelands (Fig. 2) thereby assuring variation in productivity will be considerable both within and between years (Figs 3 and 4). The resulting effect is that averages, such as average herbage production, average quality of diet, average weaning weights, etc., are in many instances only of limited value in the decision making process. The challenge to grazing

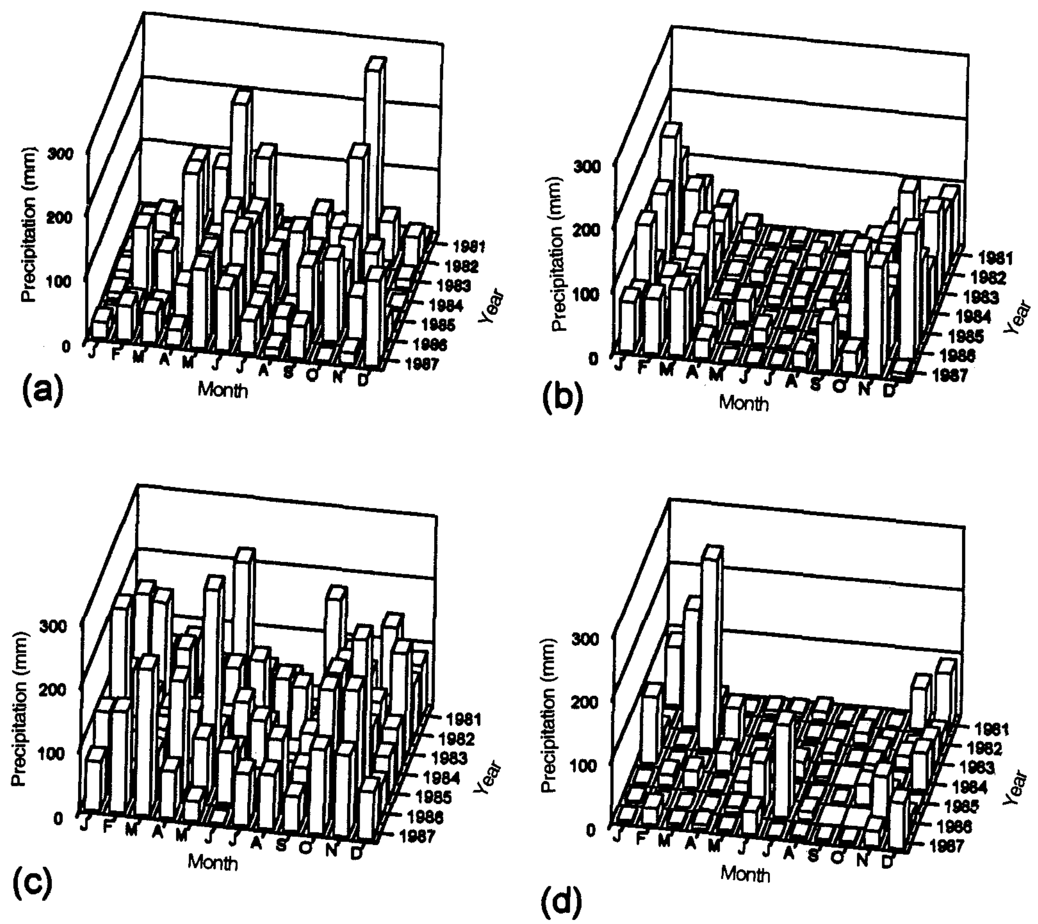

Fig. 2. Monthly precipitation (mm) from 1981 through 1987 at: a) Texas Experimental Ranch, U.S.A. (from Heitschmidt *et al.* 1990); b) Pretoria, South Africa; c) Buenos Aires, Argentina; and d) Alice Springs, Northern Territory, Australia [from Global Historical Climatological Network (http://cdiac.esd.ornl.gov/ghcn/ghcn.html)]. Data demonstrate typical levels of temporal uncertainty encountered in many rangeland ecosystems relative to abiotic growing conditions.

managers centres around capturing opportunities and avoiding pitfalls arising from deviations from norms (e.g. see Foran and Stafford Smith 1991, Danckwerts and Tainton 1993, Pickup and Stafford Smith 1993, Danckwerts and King 1984, Fouche *et al.* 1985), because managing for the average will often result in financial ruin. This problem is also the primary reason the appropriateness of current year's grazing management tactics can only be assessed accurately at year's end (Pickup and Stafford Smith 1993).

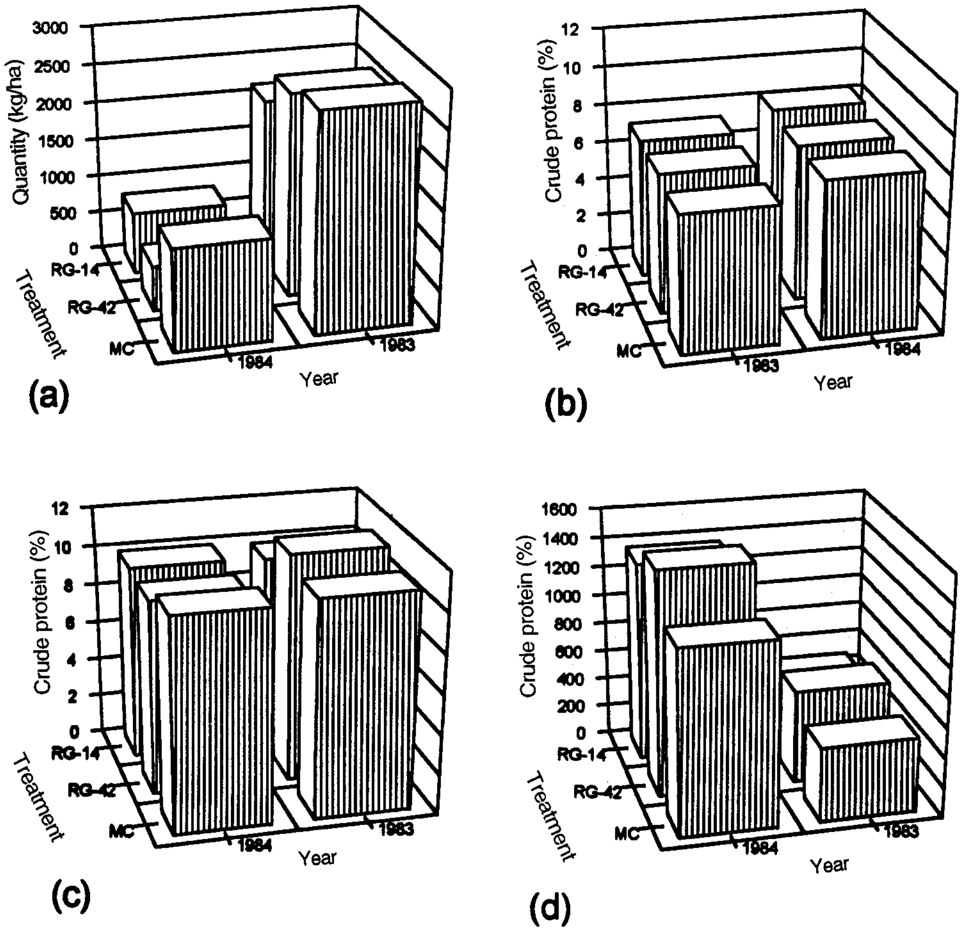

Fig. 3. Estimated late spring (a) herbage standing crop (kg/ha), (b) herbage standing crop crude protein content (% CP), (c) crude protein content of beef cattle diets (% CP), and (d) beef cattle crude protein intake (g CP/day) in 1983 and 1984 at the Texas Experimental Ranch on clay loam range sites located in a heavily stocked 1-herd, 14-paddock rotational grazing treatment (RG-14), a simulated heavily stocked 1-herd, 42 paddock rotational grazing treatment (RG-42), and a moderately stocked 1-herd, 1-pasture continuously (MC) grazed treatment (from Heitschmidt *et al.* 1987a and b, Walker *et al.* 1989, McKown *et al.* 1991). Data demonstrate typical levels of temporal variation encountered in rangeland ecosystems relative to interaction effects of management and abiotic growing conditions on important production variables.

The third major constraint centres on the process of selective grazing. All animals are selective feeders due to the phenomenon of preference. Preference is a relative term describing the discretionary behavior of grazing animals in the selection of various plants or plant parts over others (Hodgson 1979, Society for Range Management 1989). Selective grazing is a major factor affecting rate, direction, and magnitude of ecological succession in species rich rangeland environments, because the competitive abilities of individual plants are altered by frequency and severity of defoliation (e.g. see Chapman and Lemaire 1993, Briske and Silvertown 1993, Brock and Hay 1993, Briske and Richards 1995). Thus, it is important that the 'balance' between solar energy capture and harvest (i.e. defoliation) be such that it drives ecological succession in a direction that ensures the long-term sustainabilty of the grazing resource.

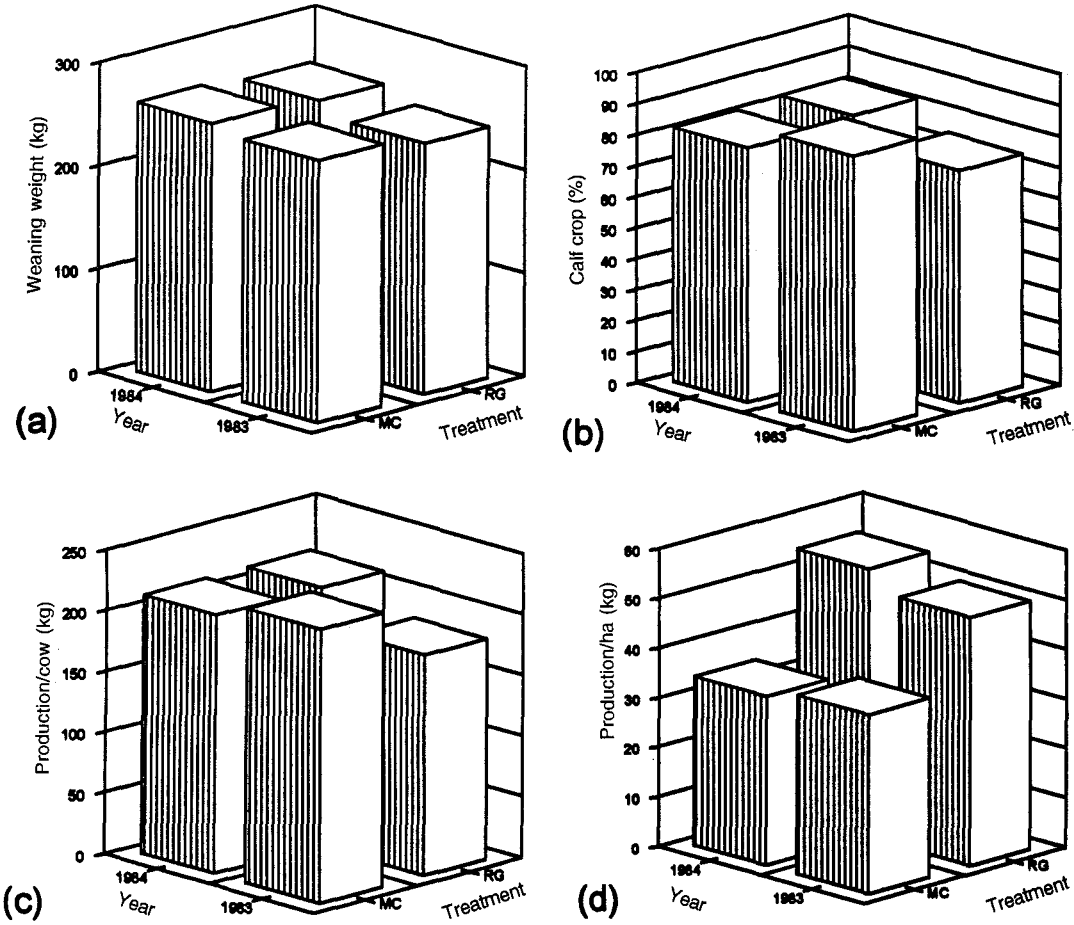

Fig. 4. Estimated (a) calf weaning weights (kg), (b) calf crops (%), (c) production per exposed cow (kg), and (d) production/ha (kg) in 1983 and 1984 in RG and MC treatments described in Fig. 3 (from Heitschmidt *et al.* 1990). Data demonstrate typical levels of temporal variation encountered in rangeland ecosystems relative to interaction effects of management and abiotic growing conditions on important livestock production variables.

Grazing tactics for attaining ecological sustainability

The fundamental principle of grazing management is to control the frequency and severity of defoliation of individual plants (Heitschmidt and Walker 1982). The principle factor controlling such is grazing pressure which is defined as the ratio of forage demand to forage available for any specified forage at any instant (Heitschmidt and Taylor 1991). The inclusion of the phrase 'any specified forage' in this definition alters the definition slightly from previous definitions (Booysen 1967, Hodgson 1979, Scarnecchia and Kothmann 1982, Society for Range Management 1989, Forage and Grazing Terminology Committee 1991), but we believe this is necessary because it incorporates the concept of preference (i.e. selective grazing) into the definition. This is critical because of the interaction effects of selective grazing on both ecological succession and the nutrient status of a grazer. As such, control of grazing pressure is a major factor affecting both the ecological condition of rangeland ecosystems and level of animal production.

Most management tactics utilized to alter grazing pressure focus on altering forage demand rather than forage availability. It should be recognized, however, that grazing pressure can be altered by increasing or decreasing forage availability over time and space. Common tactics used for such include seeding of highly productive species, fertilization, and fire management. But for the purposes of this paper, focus is on animal management tactics, and as such, it can be seen that grazing pressure varies primarily as a function of the 1) temporal and 2) spatial distribution of various 3) kind/class and 4) number of animals present (Heitschmidt and Taylor 1991).

Grazing pressure varies over time largely because of temporal variation in forage availability arising from differences in magnitude of forage production and seasonal growth dynamics. The most common tactics utilized to control grazing pressure over time are seasonal adjustments in forage demand which may range from zero (i.e. complete rest) to moderate levels on a continuous basis (i.e. yearlong continuous grazing) to very high levels on an intermittent basis (e.g. intensive early stocking strategies and one-herd, multi-pasture grazing systems).

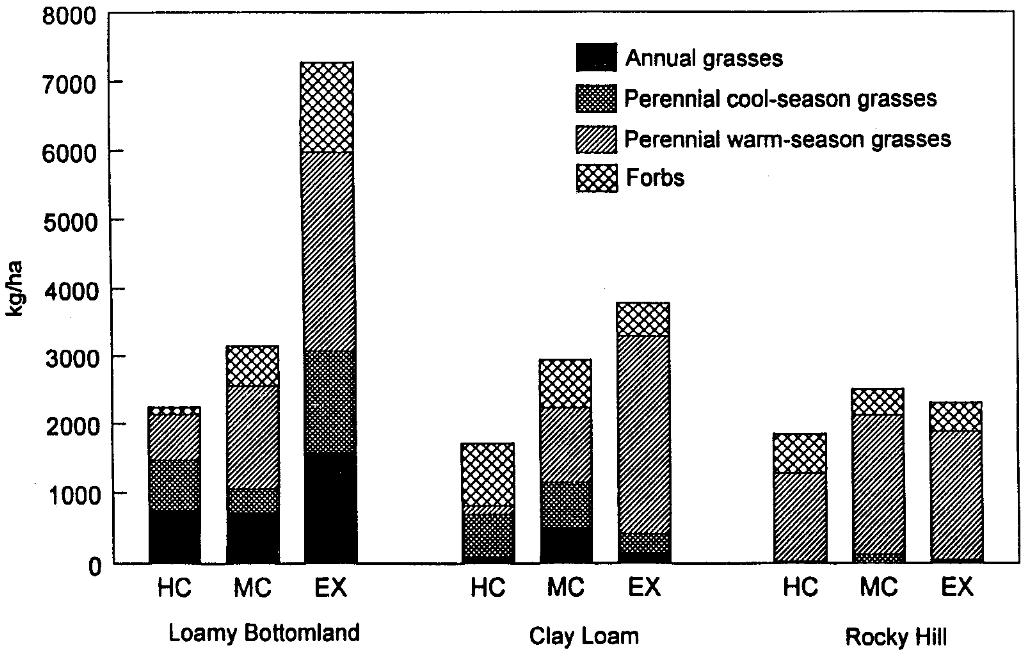

Fig. 5. Single year estimates of aboveground net primary production (kg/ha) by functional group for three range sites (i.e. loamy bottomland, clay loam, and rocky hill) in three long-term (25 years) grazing treatments [i.e. yearlong continuous grazing at heavy (HC) and moderate (MC) rates of stocking and no grazing (EX)] at the Texas Experimental Ranch (from Heitschmidt *et al.* 1985). Data demonstrate typical levels of spatial variation encountered in rangeland ecosystems relative to interaction effects of management and abiotic growing conditions on primary productivity.

Likewise, grazing pressure varies across space because of differences in forage production among spatially separated plant communities. These differences in forage production result from spatial differences in plant species composition and/or plant densities and/or growing conditions (Fig. 5). It should also be recognized that differences in plant species composition within and among sites can impact grazing pressure because of differences in mix of preferred and non-preferred forages. Cross fencing and strategic placement of salt, mineral, and watering facilities are common tactics used to alter forage demand across space.

Mix of kind and/or class of animal can also impact grazing pressure in two distinct manners. Firstly, because preferences for various plant species and/or plant parts vary widely as a function of kind and/or class of animal, forage demand and thus grazing pressure on any given stand of forage will vary depending upon kind and/or class of grazing animal present. Also, it is well known that topography influences animal use patterns and that landscape utilization patterns vary depending upon kind and/or class of animal.

Lastly, number of animals affects grazing pressure because of its direct impact on forage demand with demand increasing or decreasing in direct response to increasing or decreasing numbers of animals. Because of this direct relationship, change in number of animals is probably the most common management tactic employed to alter grazing pressure.

In summary then, it can be seen that the fundamental challenge to grazing managers arises from the need to balance the antagonistic relationship between solar energy capture and harvest efficiency processes in an environment of ecological uncertainties. Management tactics designed to assist in balancing these relationships centre around controlling grazing pressure by altering the kinds and numbers of grazing animals over both time and space. The essence of grazing management and the long-term success or failure of any and all grazing management strategies hinges upon management's ability to control the frequency and severity of defoliation of individual plants over time and space in such a manner so as to meet desired goals.

Grazing management and social sustainability

Grazing management as a social process

Grazing management is a social process by virtue of its human component. Graziers must deal with social systems and associated social dilemmas just as they must deal with ecological systems and associated ecological dilemmas.

Social challenges

The major social dilemma affecting graziers centres around the impact that ever-increasing human desires have on management of natural resources such as rangelands. Although the purpose of any form of agriculture is to provide food and fibre for humans, production incentives vary depending upon cultural setting. For example, in the most basic subsistence agricultural settings, production incentives are closely linked to survival of individuals and their descendants. In such instances, other incentives do not play a major role because, as Maslow (1954) argued, survival is the most basic goal of an individual since higher level goals, such as spiritual tranquillity and social status, are not of major concern until survival is assured. Conner (1991) goes on to argue that until survival is assured, development of sophisticated institutions and technologies (e.g. economic systems) will be limited thereby encouraging an opportunistic approach in the management of rangeland ecosystems. The social dilemma in this instance is that the increasing human desire is to survive, and as such, all available resources, including natural resources such as rangeland, are managed for short-term gains (Nores and Vera 1993). Thus, conservation and long-term sustainability suffer.

On the other end of the human well-being spectrum, the social dilemma is quite similar although somewhat disguised by the presence of an economic system. In such instances, human desire is to garner economic well-being (i.e. money) in order to purchase desired goods and services. Therefore, maximizing profit is a common goal and with inadequate knowledge of the long-term impacts of poor resource stewardship, the resulting effect is precisely the same as that in the subsistence agricultural setting; that is, conservation and long-term sustainability suffer. In fact, it can be reasoned that intensity of grazing on most rangelands would be very low were it not for the need to meet ever increasing human desires. But as Conner (1991) pointed out, "the ecological principles regulating the rate and extent of deterioration of ecological condition class, are functionally constant regardless of whether over-grazing occurs in a primitive or sophisticated society."

It should be noted also that economics is largely a measure of what members of society believe. The value of a good or service is what society believes it is worth. This value assessment is based upon society's integrated beliefs about both the current and future value of a good or service. Thus, values change depending upon societies' demands. For example, in the basic subsistence agricultural setting outlined above it may be argued that environmental degradation in general, and of rangelands specifically, is primarily the result of poverty coupled with human population pressures (e.g. see Motsamai 1993, Dasgupata 1995, Martinez-Alier 1995, Pearce *et al.* 1995, Plucknett and Winkelmann 1995). The result in these instances is that little or no value is given to rangeland resources as a provider of any goods or services other than food and shelter for the current human population. Similarly, there are societies wherein number of grazing animals is a measure of social wealth; thus, demand of rangeland resources is expanded in these instances to include the amenity of providing food for grazing animals as a means of maintaining social wealth.

Although most people readily recognize the existence of different value systems among different social systems, few recognize the magnitude of differences within a given society. Even well-trained, highly objective scientists can view the same phenomenon and arrive at greatly differing conclusions largely because of differences in their value systems. For example, Johnson and Mayeux (1992) argue that paleoecological evidence suggests ecosystems are inherently unstable. They conclude that: "Some question man's right and capacity to manipulate the natural environment and advocate a hands-off approach. But the paleoecological and biogeographical sequences reviewed suggest there are few if any, truly stable and natural plant assemblages. We must now be bold enough to accept the challenge of shaping and synthesizing new ecosystems even in the natural environment." This conclusion and subsequent recommendation is in stark contrast to the position of Noss and Copperrider (1994) who believe nature itself has spiritual and ethical value, exotic species are a threat to native plant communities, and that disturbed "unnatural" ecosystems should be restored to their natural condition. They believe nature can manage the land better than humans and they take issue with the paradigm that humans can improve upon nature particularly through technology.

These two contrasting positions are a reflection of value differences between traditional natural resource disciplines and the emerging discipline of conservation biology. It is a dichotomy of values underlaid by differing paradigms (Table 1) in that traditional natural resource management paradigms are underlain by utilitarian values whereas conservation biology paradigms are underlain by the inherent value of nature itself (e.g. see Kennedy *et al.* 1995, Box 1995). As a result of these value differences, conservation biologists readily address nature values in most of their public communications whereas traditional resource scientists tend to avoid such discussions (Erenfeld 1992).

But regardless of value system, the fundamental problem in natural resource management settings is the same, that being a lack of 'perfect' ecological knowledge (Dovers and Handmer 1995). This is what ecological (i.e. biophysical) economics are about in developed societies. Basically, ecological economists argue that the above scenarios arise from the inability of current free-market systems to deal with the functional aspects of nature and natural resources.

Table 1. Examples of changing values, images and perceptions in rangeland management arena from 1960s to 1990s (from Kennedy *et al.* 1995).

Elements:	1960s	1990s
Dominant paradigms	Single resource planning and management for short-term goals -- within long-term multiple use constraints. Rangelands, especially desert systems, perceived as having lower values than agricultural, pasture, or forest lands.	Integrated resource planning for many social values; with increase public involvement. Rangelands valued for diverse uses and noncommodity, as well as commodity values.
Good rangeland looks like...	Intensive fence, water and access 'improvements' to increase forage production and to illustrate investment in the land (good stewardship)	Extensive and subtle development-touch the land lightly
Guiding management models	Livestock is the focus and the primary product Good range condition in terms of livestock production	Livestock grazing is a tool (process) to manage and a long-term beneficiary of healthy ecosystems. Ecological status and desired future plant communities for multiple resource values
Dominant time	Annual reports and short-term (e.g. 5-10 year). planning	Long-term outlook and desired future conditions (e.g. 10-50 year)
Dominant space dimension	Administrative or jurisdictional land units (e.g. allotment or districts)	Focus on ecological landscape units (e.g. hierarchical landscape units ranging from global to specific sites)
Respected rangeland manager role-models and heroes	'Range Boss'--tough, individualistic, self-sufficient heroes and loners	Era of ID-teams, cooperators, partners, and public involvement
Land, labor capital conditions	Scarcity of trained range managers	More abundant and diverse rangeland ecosystem managers available.

Ecological economics theory differs from standard economic theory in that it attempts to more fully factor the role of natural resources into the economic process (Pearce 1987, Common and Perrings 1992). Proponents of ecological economics contend that "the most obvious danger of ignoring nature in economics is that nature is the economy's life support system, and by ignoring it we may inadvertently damage it beyond repair" (Costanza and Daly 1987). Ecological economists also contend that a major problem with the free-market system stems from social traps (Costanza 1987). A social trap is any situation in which short-term, parochial reinforcements guiding individual behaviour are in conflict with the long-term, 'best interests' of an individual and/or society as a whole (Platt 1973, Cross and Guyer 1980, Teger 1980). Although there are technically a number of types of social traps (Cross and Guyer 1980), all are related to the failure of an individual or society as a whole to correctly grasp the long-term impact of a short-term or series of short-term events on their personal welfare. As such, they argue that discount rates cannot properly reflect the future value of a resource without infallible knowledge of the future. Sagoff (1981) argued that, "economic methods cannot supply the information necessary to justify public policy. Economics can measure the intensity with which we hold our beliefs; it cannot evaluate those beliefs on their merits" (from Pearce 1987). Cleveland (1987) traced the historical development of ecological economics and in so doing concluded, "economics can no longer afford to ignore, downplay or misrepresent the role of natural resources in the economic process. In the final analysis, natural resources quality sets broad but distinct limits on what is and what is not economically possible. Ignoring such limits leads to the euphoric delusion that the only limits to economic expansion exist in our own minds."

Most economists, however, do not believe that the presumed existence of an environmental crisis necessitates the need for the development of new economic theories and systems to replace current systems (e.g. see Baden 1994, Myers and Simon 1994, Sagoff 1995). For example, some argue environmental degradation in general, and on rangelands in particular (Hess 1992), results from absence of private ownership. The fundamental argument is that when no one owns it, no one takes care of it (Marzulla 1994). An innovative group in the U.S.A. has begun to address this issue in terms of air pollution; they are trading clean air allowance futures on the Chicago Board of Trade! Is anyone interested in trading public rangeland ecological condition futures?

In summary then, it can be reasoned that the social dilemma of grazing management stems largely from two phenomena: 1) supply side management tactics designed to meet ever increasing human demands for goods and services: and 2) potential failure to accurately factor long-term ecological costs, such as resource deterioration due to excessive exploitation, into present day value systems. Although this dilemma is obvious in subsistent societies burdened by excessive human populations, it is also an insidious trait of affluent societies with complex economic systems. For example, in most affluent societies there is strong public demand for ample supplies of cheap, high quality food and fiber. Unfortunately, many members of such societies naively believe these production goals can be reached utilizing lenient use ecosystem management strategies. Moreover, many members subscribing to this paradigm also subscribe to the misconception that 'natural' ecosystem management strategies are characteristically lenient. Thus, they incorrectly conclude that most current grazing management tactics are incompatible with nature. In one sense the proponents of this position are correct; managed livestock grazing is not the same as pre-European unmanaged grazing and that may be a blessing. Consider, for example, the following quote from the journal of LaRocque, a British trader and spy, as he crossed the Tongue River in Montana, U.S.A. in September, 1805: "There was little or no wood here on the river, with the exception of a few cottonwoods scattered here and there and grass was completely lacking....We had to cut down three cottonwoods and make them (the horses) eat the bark" (from Wood and Thiessen 1985). This is but one of a multitude of early explorers' declarations that indicate the historical condition of rangelands was not as often perceived (e.g. see Kay 1995, Hart and Hart 1996). Still, failure by society in general to accept such a conclusion renders many grazing management tactics as socially unacceptable and thus by definition unsustainable.

Grazing tactics for attaining social sustainability

Ecological sustainability is a prerequisite to social sustainability because a practice that is not ecologically sustainable will be neither economically sustainable nor socially acceptable over the long-term. But the question we pose is: can control of the frequency and severity of defoliation of individual plants improve the social sustainability of rangeland agriculture (i.e. grazing)? More specifically, we are asking: What are the social impacts of manipulating the 1) temporal and 2) spatial distribution of various 3) kinds/class and 4) number of livestock in a rangeland setting?

Although number of animals is perceived generally to be the overwhelming factor affecting profit and ultimately economic sustainability, we suggest selection of species of grazing animal is most often the first decision made by graziers in the hierarchial decision tree of grazing management. But because this decision is often influenced more by tradition than economics, the decision may be unconsciously irrelevant. Thus, number of animals is generally accepted as the overwhelming factor affecting both the ecological and social sustainability of rangeland agricultural enterprises.

The effects of animal numbers on economic stability are related to both economic profits and risks as well as social acceptability. As has been shown time and again, as number of animals per unit area of land per unit of time increases (i.e. stocking rate), individual animal performance gradually declines while production per unit area gradually increases to a maximum before beginning a rapid decline (Fig. 6). Assuming rate of decline in individual animal performance with increasing rates of stocking is linear or near linear, then the stocking rate at which maximum production per unit area will be achieved will be about halfway between the critical stocking rate [i.e. stocking rate at which individual animal performance first begins to decline (Hart 1978)] and that at which animal performance is zero. It has been shown also that as rate of stocking increases, costs of production tend to increase (Fig. 7). Thus, maximum profits are realized generally at rates of stocking slightly below those required to maximize animal production per unit area (Wilson *et al.* 1984). But because of temporal and spatial variation in quantity and quality of forage, optimal rates of stocking vary broadly over time and space (Fig. 6). This in turn means economic risks increase dramatically as rates of stocking approach theoretical maximums.

The above concepts have been demonstrated in a wide array of rangeland environments (e.g. see Hart *et al.* 1988, Stafford Smith and Foran 1993, Hatch and Tainton 1993). We demonstrated the concepts in a series of set stocked cow-calf production scale studies at the Texas Experimental Ranch (Whitson *et al.* 1982, Heitschmidt *et al.* 1990). In the latter study, we found over a six year period (1982-1987) that production per cow from yearlong grazing treatments stocked at moderate (MC) and heavy (HC) rates of stocking averaged 216 and 211 kg, respectively, whereas production per unit area averaged 35 and 45 kg/ha, respectively. Likewise, residual returns (i.e. net returns to land, management, and profit) in the HC and MC treatments averaged $61 and $70 on a per cow basis, respectively, and $13 and $11 on a per hectare basis. Thus, during these six years it might be concluded that the HC treatment was the most economically sustainable treatment, and based on averages, this is true. However, during this same period residual returns from the HC treatment ranged from $-18 to $+96/cow and from $-3 to $+21/ha whereas the range in the MC treatment was from $+14 to $+109/cow and $+12 to $+17/ha. Therefore, if economic risk is a component of sustainability, and most would agree it is, then it seems reasonable to conclude that the moderately stocked treatment was in fact more economically sustainable than the heavily stocked treatment. It should also be noted that ecological studies in these same treatments showed ecological condition, relative to seral stage, was higher in the MC than HC treatment and ecological trend was steady in the MC treatment but declining in the HC treatment (Heitschmidt *et al.* 1985, 1989). As such, it can be reasoned that the social acceptability of the heavier stocking rate would be at risk relative to the more moderate rate of stocking.

The effects of mix of animal species and/or classes on economic sustainability is not as clearly documented as the effect of number of animals. Still, there is an abundance of data that shows clearly that multi-species grazing often enhances production per unit area of grazing land (e.g. see Nolan *et al.* 1993, Walker 1994). This is accomplished by increasing harvest efficiencies and even in the absence of quantitative data, it can be reasoned that a mix of grazing animals may enhance economic stability by improving profits per unit area through improved animal production. Moreover, economic risk may be reduced because the probability of catastrophic losses occurring would be less for a set of diverse enterprises than for any single enterprise (Conner 1991).

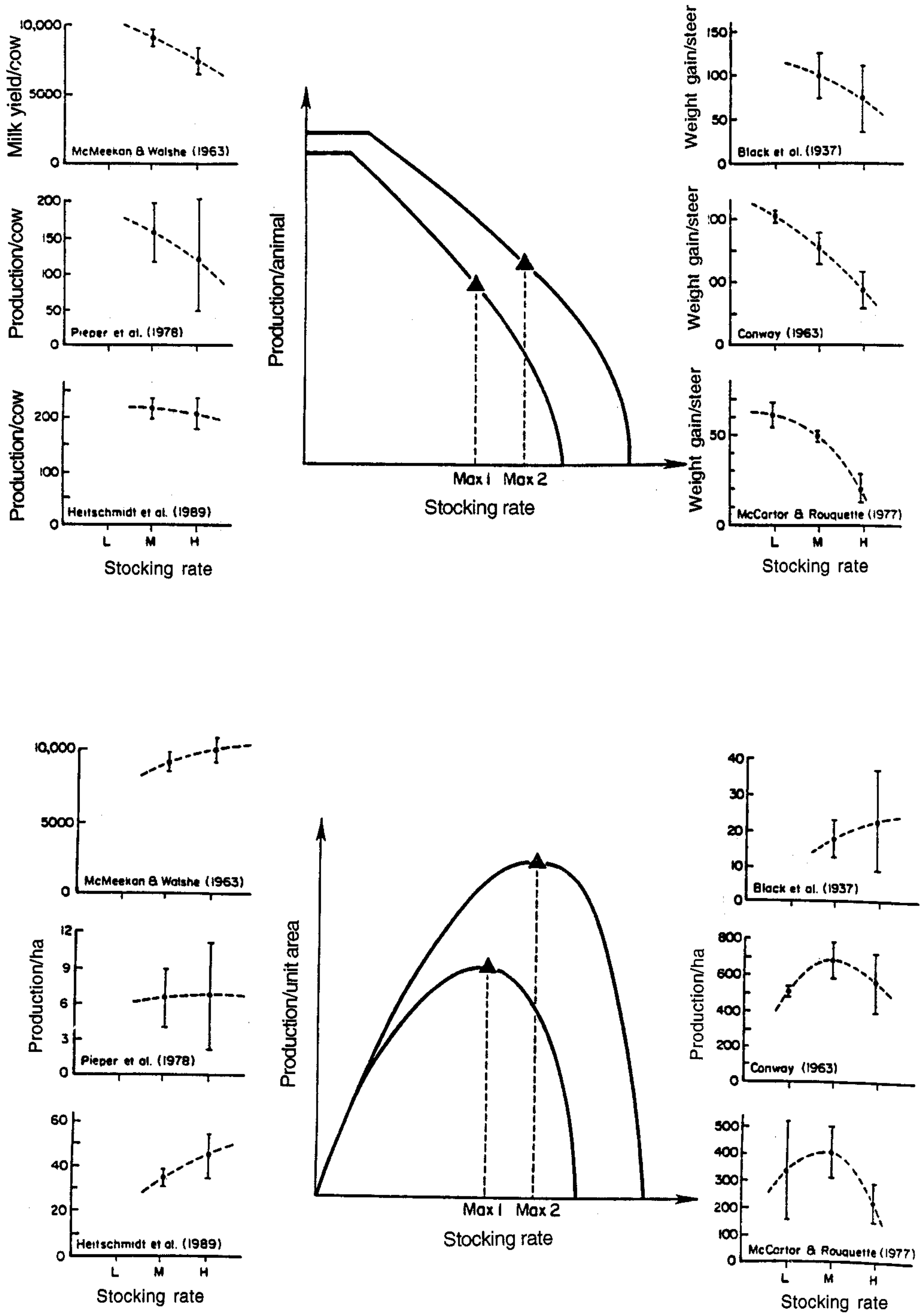

Fig. 6. Conceptual models of functional relationships between stocking rate and (a) production/animal and (b) production/unit area of land. Upper line is conceptual model depicting functional relationship during periods of abundant forage production whereas lower line depicts relationships during periods of limited forage production. Max 1 and Max 2 approximate rates of stocking at which production/unit area is maximized depending upon relative levels of herbage availability. Adjoining figures in right- and left-hand columns reflect fundamental

.....*continued*

Fig. 6. *continued*
relationships between light (L), moderate (M), and heavy (H) stocking rates and production/animal (kg) and production/ha (kg) as derived from studies by Pieper *et al.* (1978) and Heitschmidt *et al.* (1990) (yearlong grazing, rangeland); McCartor and Rouquette (1977) (seasonal grazing, annual pasture); Black *et al.* (1937) (seasonal grazing, rangeland); and Conway (1963) and McMeekan and Walsh (1963) (yearlong grazing, grass-clover mixed pasture). Vertical lines represent 1 standard deviation of annual means. Note that in all instances except McCartor and Rouquette (1977), deviations from performance means increase as rates of stocking increase thereby indicating ecologically optimal rates of stocking vary within and between years (from Heitschmidt and Taylor 1991).

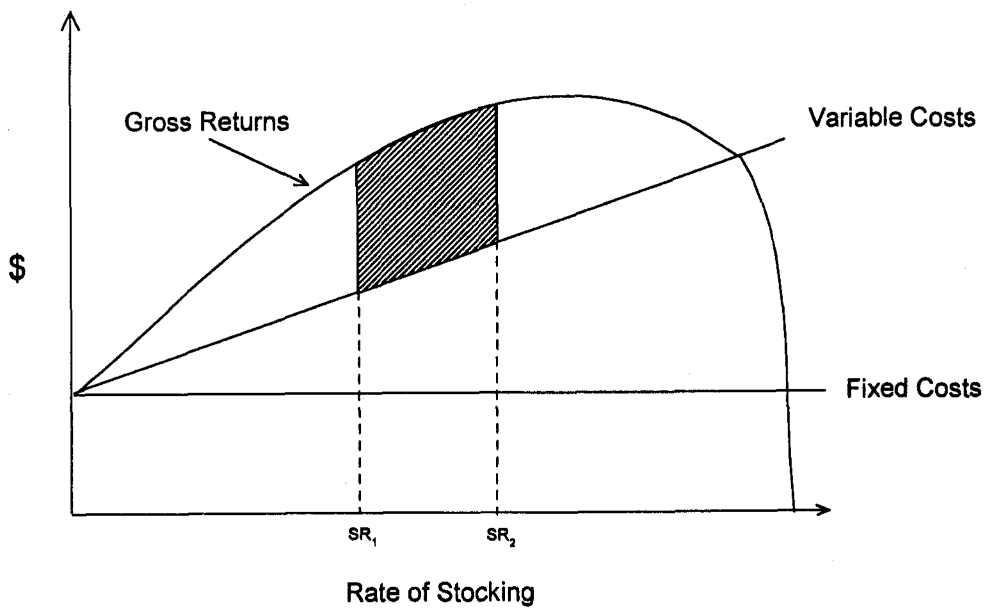

Fig. 7. Theoretical relationship between rate of stocking and economic profits (after Wilson *et al.* 1984, Conner 1991). Rates of stocking between SR1 and SR2 represent economic optimal rates of stocking assuming costs and returns remain near constant. However, because costs and returns vary as a function of both quantity of resources used (e.g. supplemental feed, etc.) and produced (e.g. weaned calf crop, production/ha, etc.) and market prices, economic optimal rates of stocking vary within and between years.

The effects of alterations in temporal and spatial distributions of animals on economic stability and social acceptance are even less well documented than the social impacts of variations in number and kind/class of animals. Certainly, temporal patterns of distribution of animals across a landscape can affect magnitude of animal production and ultimately economic profits depending upon fundamental relationship between production costs and revenues. Important matters of concern are the costs associated with redistributing animals over time and space (e.g. cost of fencing, strategic placement of mineral feeders and watering facilities, implementation of animal management strategies to ensure occasional periods of rest, etc.) and revenues associated with individual animal performance and production per unit area variables.

Grazing systems are a specialized form of grazing management that includes a series of scheduled periods of grazing and rest (Society for Range Management 1989). As such, the 'success' of a grazing system is functionally dependent upon the concurrent interaction effects of a minimum of two grazing tactics (e.g. temporal x spatial distribution, temporal distribution x number of animals, temporal distribution x spatial distribution x number of animals, etc.). Grazing systems can also impact social sustainability by their impact on profits, economic risks, and social acceptance. This too has been demonstrated at the Texas Experimental Ranch wherein the economics of the HC and MC treatments were contrasted to those in a 4-pasture, 3-herd deferred rotation (DR) grazing treatment stocked at a moderate rate (Whitson *et al.* 1982) and a 16-pasture, 1-herd rotational (RG) grazing treatment stocked at a very heavy rate (Heitschmidt *et al.* 1990). During the same 6 years discussed previously (1981-1987), production per cow in the DR treatments averaged \$93 and ranged from \$51 to \$124 as compared to an average in the RG treatment of \$63 and a range of \$17 to \$88. On the other hand, production per hectare averaged \$16 in both treatment ranging from \$9 to \$22 in the DR treatment and from \$5 to \$23 in the RG treatment. Thus, when the four treatments (i.e. HC, MC, DR, and RG) are compared, it can be reasoned that the greatest profit potential lies in the DR and RG treatments (Fig. 7). But it can also be seen that risk avoidance was greatest in the DR treatment. Thus, based strictly on economics, it can be concluded that the DR treatment was the most sustainable of the four treatments. But what about social acceptance? We believe both moderately stocked treatments (i.e. MC and DR) are socially more acceptable to society at large because they are aesthetically pleasing. Associated research in these treatments pastures (Heitschmidt *et al.* 1985, 1989) showed ecological condition, as measured by plant species composition (Soil Conservation Service 1984), was fair in the HC treatment and good in all other treatment pastures. Thus, one might conclude that only the HC treatment would not be socially acceptable. But we would suggest that plant species composition does not impact society's acceptance of a given grazing practice nearly as much as amount of standing biomass, ground cover, number of faecal patties, etc. We would argue, therefore, that neither the heavily stocked HC nor RG treatments would be very socially acceptable since standing crop and ground cover in both were substantially less than in the moderately stocked MC and DR treatments. If true, then it seems reasonable to conclude that current grazing technology requires moderate rates of stocking be employed to insure rangeland agriculture (i.e. grazing) is ecologically sound, economically viable, and socially acceptable.

Grazing management and the future

Another dilemma

Visions are a reflection of beliefs. Visions associated with management of natural resources, such as rangelands, are philosophically underlaid with two fundamentally different hypotheses. The first hypothesis is often referred to as the omnipotent technology hypothesis. This hypothesis embraces the concept that resource depletion automatically sets into motion a series of economic forces that alleviate the effects of depletion on society as a whole (Cleveland 1987). It is the central underlying theme supporting the thesis that technology will prevail. Contrary to this hypothesis is the omnipotent ecological constraint hypothesis (Heitschmidt 1991). Central to this hypothesis is the belief that technology can neither overcome nor circumnavigate certain ecological processes that constrain or limit human well-being. It is the fundamental hypothesis driving ecological economics.

The dilemma we faced in the writing of this section is that we could not agree fully as to which of the above hypotheses should dominate our vision. We concluded in the end, however, that probably the 'safest' vision should be based on a combination of the two hypotheses. To this end, we are optimistic that technological advances will be made that will result in significant improvement in the management of grazed agroecosystems. However, we do not believe these advances will be of the sort that will allow society to effectively convert massive portions of indigenous rangeland into fully sustainable agronomic and/or tame pasture production systems. We believe rangelands and rangeland agriculture are here to stay.

One area wherein our vision is very cloudy relates to the potential role that feed grains may play in the future in the finishing phase of livestock production. Currently, modern day agriculture is highly dependent on the availability of cheap fossil fuels (e.g. see Pimentel 1984, Heitschmidt *et al.* 1996) and one of the great unknowns is whether technology can continue indefinitely to provide cheap sources of energy for the conduct of agriculture. This is particularly important in those animal production systems that are highly dependent on feed grains as a foodstuff. For example, it is estimated that current U.S.A. beef cattle production systems typically utilize 4.8 kg of grain, 30,000 kcal of cultural (e.g. fossil fuels) energy, and 3,000 L of water to produce 1 kg of meat (Durning and Brough 1991). If cultural energy should become limiting, a shift in the ecological role of humans may be necessary. This is because humans are omnivorous animals that most often occupy either the second (herbivorous) or third (carnivorous) trophic level of food chains or both the second and third levels (omnivorous). Occupation of trophic levels greater than the second is in many instances a luxury afforded to only a privileged few, that being those living in an environment where human food demand is well below supply. However, when human food demand begins to exceed supply, the Laws of Thermodynamics dictate that humans occupy the second trophic level to the maximum extent possible. In such instances, the role of animal agriculture is relegated to that of energy brokering which is the process of converting low quality human feedstuff (e.g. corn stalks, spoiled grains, rangeland forages, etc.) into high quality human feedstuff (e.g. meat, milk, eggs, etc.). Thus, it can be reasoned that with an ever increasing human population, animal agriculture may eventually be forced to function strictly in an energy brokering capacity in accordance with the omnipotent ecological constraint hypothesis. Of course the alternative paradigm is that the omnipotent technology hypothesis will dominate and new sources of energy will be developed to replace current finite supplies of fossil fuels and/or other new technology will be developed to reduce agriculture's considerable dependence on cultural energy inputs. Only time will tell.

The vision

We believe grazing management technology will be developed that will allow us to improve production efficiencies on three fronts, specifically: 1) capturing of solar energy (i.e. primary production); 2) harvest efficiencies (i.e. proportion of primary production harvested for secondary production); and 3) assimilation efficiencies (i.e. proportion of harvested primary production actually converted into secondary production). These improvements will be realized through technological breakthroughs on four fundamental components of rangeland agroecosystems, chiefly the: 1) primary producer (i.e. plants); 2) primary consumers (i.e. grazing animal); 3) abiotic; and 4) human (i.e. management) components.

First, we believe significant advances will be made in the development of new plant germplasm (e.g. see Peacock 1993, Schultz-Kraft *et al.* 1993, Hodges *et al.* 1993) that will be used largely to supplement rangeland forage based diets during periods of nutrient shortfalls. These forages will enhance both efficiency of primary and secondary production. The principal means of increasing primary production will be through increases in quantity of forage produced whereas the principal means of increasing secondary productivity will be through increases in quality of forage (e.g. see Ulyatt 1993).

Second, we believe correspondingly significant advances will be made in level of animal production through the manipulation of animal germplasm. We believe improvements in assimilation efficiencies will be realized directly by manipulating the genetic makeup of the grazing animal and indirectly by manipulating the genetic makeup of ruminant microbial populations (e.g. see Cheng *et al.* 1995). Currently, a large portion of the developed world's animal germplasm has been selected primarily on their ability to convert feed grains into highly desirable animal products for human consumption. We believe, however, that biotechnology will provide us with opportunities to develop ecologically superior grazers, that is animals that 'fit' rangeland environments. This concept is a fundamental paradigm shift away from the 'we will fix the animal's environment to meet the animal's genetic requirements' to 'we will fix the animal's genetic requirements to match the animal's environment.' Similarly, we anticipate that new animal health monitoring and treatment technology will be developed that will improve animal performance (i.e. improved assimilation efficiency) substantially above current standards.

Third, we anticipate that a wide array of user-friendly, expert systems will be developed to assist graziers in their decision making (e.g. see Gillard and Monypenny 1990, Foran and Stafford Smith 1991, Stuth *et al.* 1993, Wight and Hanson 1993, Hart and Hanson 1993). We believe also that future technology will help eliminate much of the production uncertainty arising from our inability to accurately assess current and future grazing conditions relative to quantity and quality of forage available (McKeon *et al.* 1990). Although we would like to believe remote sensing technology will be refined to a level whereby it will be useful in the day to day management of small tracts of land, we do not believe this will happen in the foreseeable future. We believe, however, significant advances in climate forecasting will be made (e.g. see Hunt 1991, Hanson and Wight 1993). We believe major advances in climate forecasting will enhance the ecological and social sustainability of rangeland agriculture more so than essentially any other visioned technological advancement because it will allow timely stocking rate adjustments to be made (McKeon and Howden 1992). It is well known that variable moderate and heavy rates of stocking are ecologically and economically superior to set moderate and heavy rates of stocking (e.g. see VanTassel *et al.* 1987, Hart 1991, Buston and Stafford Smith 1996, Ash and Stafford Smith 1996) providing adjustments are made in a timely manner. The need for significant advancements in weather forecasting is readily apparent when one considers that fluctuations in the price of orange juice futures on the Chicago (U.S.A.) Board of Trade are a more accurate prediction of time of injurious freeze conditions occurring in Florida than the official US Weather Bureaus' forecast (Roll 1984). Still, it is exciting to consider the benefits that accurate assessment of current forage conditions and climate forecasting conditions would provide rangeland agriculture relative to improving profit margins while reducing both economic and environmental risks.

Fourth, we believe new management technology will be generated that will allow grazing managers to control the 1) temporal and 2) spatial distribution of various 3) kinds/classes and 4) numbers of animals in a very cost-effective and ecologically sound manner. This vision centers around the development of remote sensing technology that will allow managers to monitor and control the spatial distribution of grazing animals on a continuous basis (Lewis and Volesky 1987). The chief advantage of this technology will be improvement in landscape use patterns in a timely manner.

Lastly, our vision of social acceptance of rangeland agriculture as an appropriate use of rangelands is very cloudy and uncertain. On the one hand it can be reasoned that rangeland agriculture will become more socially acceptable as human food demands increase and society becomes increasingly appreciative of the fact that grazing of indigenous rangelands is the most ecologically sustainable form of agriculture known. However, in contrast to this position, it can be hypothesized that future generations will be afforded the opportunity to reject using rangelands for agricultural purposes. This will be the case if growth in human food demands does not exceed concurrent growth in food supplies as a result of either slowed rates of population growth or because of major advances in agricultural technology in fields of agriculture other than rangeland. Society will then be free to manage rangeland resources for purposes other than agricultural. Although such a conclusion is worrisome to many, the possibility does exist particularly if the rangeland management profession chooses to disregard the social aspects of rangeland management (e.g. see Nores and Vera 1993, Maxwell and Laycock 1993, Stafford Smith and Foran 1993, MacLeod and Taylor 1994, Fitzhardinge 1994, Schulman and Penman 1994). Recently, Fleischner (1994) asked: "Is there an ecologically sustainable future for livestock grazing in western North America?" to which he answered, "This ultimately is a question of human values, not science." Similarly, Noss and Cooperrider (1994) wrote: "Much of the conflict over land management results from differing value systems, philosophies, and associated aspirations." Again, only time will tell!

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