ADAPTIVE SUSTAINABILITY OF LIVESTOCK PRODUCTION ON ARID AND SEMI-ARID GRASSLANDS

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ABSTRACT

Sustainability of livestock production from arid and semi-arid grasslands is threatened by breakdown of traditional pastoral systems, degradation of the vegetation and soil, unfavorable economic conditions and changing attitudes to land-use. Consistent failure of range and livestock development projects in developing countries, especially in Africa, has contributed to a lack of faith in the possibilities for improvement. Sharp criticism of 'mainstream' range management theory and practice has shaken its foundations. The inadequacy of established paradigms to deal with the issues has led to a reappraisal of basic principles of range management, of criteria for defining and judging degradation, and of the role of grazing in the functioning and integrity of rangeland ecosystems. New ideas and new directions for development are being discussed but the debate is still rather academic; most people whose livelihood depends on the grasslands are unaware of and unaffected by the intellectual storms raging above their heads. In the present review, some of the current concerns and concepts are discussed, limits to the validity of some of the newer paradigms are indicated, and the margins for adaptive sustainability are explored. It is concluded that trends in arid and semi-arid grassland management and production are determined by factors more powerful than paradigms of range ecology or theories on development dynamics. Nevertheless, the latter are important as a guide to more rational development planning and less damaging intervention by government and international funding agencies.

KEYWORDS

Pastoralism, range degradation, non-equilibrium dynamics, opportunistic management.

INTRODUCTION

For some time now, livestock production on arid and semi-arid grasslands has been widely regarded as an environmentally degrading, unsustainable form of landuse and as an unrewarding economic activity (Sandford, 1983; Ellis and Swift, 1988; de Leeuw et al., 1993; Anon., 1994). Real and imagined range degradation, increasing susceptibility to drought, low profitability and bankruptcy bring into question current range and livestock management practices. Responsibility for declining landscape and recreation values, degrading riparian habitat, brush encroachment, lower biodiversity and poorer water quality is being placed on the ranching and pastoral activities that depend on the grassland resource (Anon., 1994; West et al., 1994; Laycock, 1995). Wide fluctuations in animal numbers on African rangelands, together with deterioration and disruption of traditional controls (Behnke and Scoones, 1993), have caused severe losses and human hardship during extended drought and raised the issue of sustainability of pastoralism. "Many people believe that pastoral groups are gradually disappearing and that pastoralism is dying out as a way of life... some people believe the trend to be not only inevitable, but also desirable..." (Sandford, 1983, p. 2).

With so many signs of unsustainability, it is quite remarkable that so many people and communities still manage to earn a large part of their livelihood from extensive animal production on the arid and semi-arid grasslands of the world in both developed and less developed countries. Nevertheless, "no condition is permanent" (Harden, 1991) and the signs leave no room for complacency. Are the days of livestock production on arid and semi-arid grasslands numbered or are we misreading the signs? This issue been intensively debated in recent years (Salzman and Chouinard, 1981; de Ridder et al., 1986; Ellis and Swift, 1988; Behnke et al., 1993; Stafford Smith and Foran, 1993; Scoones, 1994). We will discuss the response of the scientific community to this question, examine the intrinsic capabilities of arid grassland systems to cope with current stress, and indicate some of the measures that promote ecological, economic and social sustainability of these systems.

SUSTAINABILITY - PAST AND PRESENT

A historical perspective. Before concluding that the present situation on these grasslands is unique in history, a glance at events from the more distant past should help to put current issues into a more sober perspective. "If one looks at the history of many dry areas, not over decades but over centuries, one sees not a trend in a single direction, but an ebb and flow of pastoral peoples... and activities as political, economic, and natural conditions changed" (Sandford, 1983). So too, does the border shift between the desert and the sown (Noy-Meir and Seligman, 1979). Over the past half century, unprecedented technical, economic and demographic developments have marginalized agriculture, especially in the developed world (Walker, 1995). Profitability has fallen and environmental issues have put a negative slant on much agricultural and pastoral practice. But this is not the first time in history that agricultural fortunes have switched. In a review covering six centuries, Joan Thirsk (1994) identified two alternating phases in English agriculture: a 'mainstream' and an 'alternative' phase (Fig. 1). The mainstream phases were marked by high demand and good prices for commodities, good profitability, agricultural expansion, including cultivation of permanent pasture; the alternative phases were marked by low demand and low prices for commodities, search for alternative crops and technologies, poor profitability, agricultural contraction, including abandonment of cultivated land and conversion to pasture. The last mainstream phase began in 1914 with the outbreak of WWI and continued (with a 'temporary' recession in the 1930's) until the early 1970's. Since then, agriculture in England and, indeed, in most developed countries, has been in an 'alternative' phase. When it will end is anyone's guess, but the current upswing of world market commodity prices may be a harbinger of the next 'mainstream' phase.

The 'alternative' phase terminology that was prominent at the last (17th) IGC included: quality products, niche markets, diversification, conservative stocking, risk reduction, environmental conservation, holism, integrated systems, management of transition (Foran, 1993). History is a poor indicator of future developments so we cannot take for granted an inevitable recovery in the form of a mainstream revival. It is therefore difficult to tell whether the current malaise is the beginning of the end, or a phase in the continuing 'ebb and flow'.

Definitions. Aridity in the grassland context implies highly variable soil moisture availability and recurrent, extended periods that are too dry for active vegetation growth. Herbage production is negligible below a minimum rainfall threshold that depends on regional conditions (r_o in Fig. 2). On 'arid grasslands' vegetation is scattered, sparse and patchy and does not form a continuous cover over the landscape; on 'semi-arid' grasslands the vegetation can develop a continuous cover in wetter years. Very roughly, in regions with cool, wet growing seasons, 'arid' would be less than 200 mm average annual rainfall and 'semi-arid', 200 to 500 mm (Le Houérou, 1993a). In regions with warm wet seasons, 'arid' would be less than 300 mm and 'semi-arid', 300 to 800 mm. The lower limit, r_o, for arid regions below which pastoralism cannot be widely practiced can be very low (e.g. Sinai) but the limit is about 50 mm in cool wet climates and 150 mm in warm wet climates. Biomass production is usually well below 2000 kg ha^{-1} (Fig. 3). The term 'dry grasslands' will be used to cover both zones.

Doomsday scenario. Arid and semi-arid grasslands have been used for livestock production for millennia in the Old World and for centuries in the New World. The concern for their sustainable use arises from the externalities that have changed dramatically during the past half century: accelerated urbanization and its associated values, population increase, along with livestock increase, and reduction of buffer zones because of greater access to areas previously protected by lack of water for livestock or by prevalence of disease; on the other hand, some of the best rangeland that was critical for survival has been lost to cultivation (Sandford, 1983; Scoones, 1993; Narjisse, 1995). The greater concentration of livestock on the shrinking available grassland has raised concern about creeping degradation of vegetation and soil. This, together with adverse effects of putative global climate change, has been the basis for predictions of eventual collapse of the arid grassland resource, especially in less developed countries (e.g. Le Houérou, 1990, 1992; Narjisse, 1995). Even where the doomsday scenario is less threatening, the cost in human welfare following disruption of pastoral societies (Galaty and Aronson, 1981) and damage to the environment is becoming unacceptable to the community at large (Anon., 1994).

Mixed signals. On the other hand, while not denying that grassland degradation has occurred in Africa, Sandford (1983) questions how serious or widespread it is and whether indeed there has been an undue increase in animal numbers on the range. Evidence of accelerated desertification in Africa has been challenged (Nicholson, 1990; Dodd, 1994) and erosion on heavily stocked African grasslands has been found to be low (Biot, 1993) or similar to that on lightly stocked grassland (Tapson, 1993). In the USA, intense debate on the condition of the rangelands has spawned a number of seminars, symposia and investigation committees (e.g. Anon., 1994; Vavra et al., 1994; West et al., 1994). Official assessments rate only 14% of the western rangelands as declining in condition (Anon., 1994). However, long-term monitoring data that can serve as an unambiguous basis for assessment are rare and there is still no consensus on whether degradation is widespread or serious.

Official livestock numbers in arid regions are not very reliable indicators of sustainability, but do give a indication of trends, at least as perceived by the monitoring authorities. In some countries animal numbers are increasing dramatically, in others they are stagnant and in others they are declining (Figs. 4 & 5). High livestock numbers may be overloading the grasslands even where animal nutrition is heavily dependent on exogenous feed grains (Le Houérou, 1992; Narjisse, 1995); declining numbers may be caused by degrading grasslands, but also by low prices for products (wool in Australia, South Africa and Argentina) or by war (Yemen, Iraq?).

Sustainability of livestock production on dry grasslands depends on the ecological robustness of the resource, economic viability of the production system, vigor of the pastoral and rural society, and pressures from other land-use interests. Adaptation to disturbance and change requires adjustments to these factors. Where successful, such continuous adjustment can be called 'adaptive sustainability'. We will try to show that ecological feedback mechanisms and judicious exploitation of the margins for management can postpone the doomsday scenario indefinitely.

ROBUSTNESS OF THE GRASSLAND RESOURCE

Thresholds of sustainability. Arid grasslands function close to a threshold of sustainability. Drought combined with heavy stocking can tip the grassland system over the threshold. This may have happened in the Australian outback during the last century when the pre-colonial open grassland and dwarf shrub communities were exposed to heavy sheep and cattle grazing that, together with drought, eliminated many species that were palatable but also sensitive to trampling and defoliation (Perry, 1968). Similarly in Patagonia, where sheep husbandry has been practiced widely over the past century, a marked decline in the number of livestock (Fig. 2) is partly ascribed to grassland degradation following drought (Oliva et al., 1995). In the Chihuahuan Desert, livestock grazing has been at least partly responsible for conversion of large areas of black grama (*Bouteloua eriopoda*) grassland to creosote bush-mesquite desert shrubland with low value as forage (Anon., 1994). An irreversible threshold is crossed whenever an upper, relatively fertile, permeable soil horizon is eroded away to expose a heavy, impermeable and infertile substrate that can only sustain a much lower level of production (Noble et al., 1984; Milton et al., 1994).

Sustainability of grassland production near the threshold of existence is indeed precarious and easily undermined. Vegetation and soils can be forced into undesirable states but seldom to extreme degradation because the climatic variability that is the reason for the bad years is also the basis for recovery in the good years.

Trade-off between production efficiency and sustainability. Complexity of arid and semi-arid grassland systems is compounded by practically unmeasurable spatial and temporal heterogeneity interacting with a large and critical stochastic dimension (Ellis, 1994). The wide fluctuations in herbage production (Paulsen and Ares, 1961; van Keulen, 1975; Behnke and Scoones, 1993) are the outcome of a cascade of constraints imposed by abiotic and biotic factors. Availability of water, mainly from rainfall, is the first constraint on vegetation and livestock production, followed by water use efficiency. Depending on the vapor pressure deficit during growth, transpiration efficiency of C_3 plants can vary between approximately 3 and 8 g m^{-2} mm^{-1} (Meinke, 1996). However, only a small part of the rainfall is allocated to transpiration. From a large data set in the dry Mediterranean and Sahelo-Sudanian zones, Le Houérou and Hoste (1977) have estimated rainfall utilization efficiency to be an order of magnitude lower (0.25 and 0.40 g m^{-2} mm^{-1}). Efficiency declines because of heavy losses, mainly from bare soil evaporation, runoff and in sandy soils, possibly some percolation beyond the rooting zone. In addition, nutrient deficiency limits growth, especially when rainfall exceeds 200 mm yr^{-1} (Penning de Vries and Djitéye, 1982; van Keulen and Seligman, 1992).

Shoot growth can be constrained not only by limits on CO2 assimilation, but also by massive allocation to roots and other underground structures (e.g. Ayarza et al., 1993) and to energy expensive secondary metabolites. In annual species the root fraction at the peak of the season is approximately 10%, but much higher in perennial plants: working in a semi-arid zone, Distel and Fernandez (1988) found that 80% of annual assimilation was invested in the roots of perennial grasses and that root turnover exceeded 100%.

Of the herbaceous shoot material produced, up to 50% can be utilized by livestock (Le Houérou, 1993a; de Ridder and Breman, 1993) but some estimates in dry regions are as low as 10 to 12% (Ellis and Swift, 1988). Utilization varies with season of use, and with weathering losses. However, in terms of conversion efficiency, dry matter availability is often of secondary importance compared to forage quality, mainly protein content and digestibility (Ellis and Swift, 1988; de Ridder and Breman, 1993). Estimates of conversion efficiency of gross energy in efficient beef and sheep production systems vary between 2.0% and 4.4% (Holmes, 1986; Rattray, 1986).

Short growing seasons, variable and predominantly low forage quality, diversion of resources to secondary metabolites, lignin, roots and reproductive structures all lead to low utilization rate of vegetative production by livestock. However, the trade-off for low overall exploitation efficiency is a more robust grassland. The secondary products that are 'harvested' from arid grasslands are a small but highly variable fraction of all the energy and nutrient resources invested in the production process (Bartels et al., 1993.). Uncertainty about the outcome is its most certain feature, but the persistence of the grassland system itself is seldom at stake.

Stress and species composition. The versatility of botanical response to multiple biotic and abiotic stresses is another defense against ecosystem degradation. Elimination of palatable, tall species, sensitive to grazing can create opportunities for species more resistant to defoliation and trampling stress (Tainton, 1988; Noy-Meir et al., 1989). As aridity and grazing pressure increase, biodiversity tends to decrease, but less so on range where livestock grazing has a long history (Milchunas et al., 1988), or not at all (Olsvig-Whittaker, 1993). Stress can induce transitions:

- from palatable to unpalatable or inaccessible (e.g. very small) species
- from palatable to less palatable species, but more resistant to grazing
- from more nutritious to less nutritious species
- from less nutritious to more nutritious species
- from perennial to annual species
- from herbaceous to woody species.

On some grasslands grazing pressure has improved forage quality (Harrington and Pratchett, 1974; Ash et al., 1993; Tapson, 1993). Other dry grasslands have responded with an increase of arborescent species, some with loss in forage value (Archer, 1994), others with gain (van Duivenboden, 1989).

Annual species, some native, others exotic invaders, dominate arid grasslands in many parts of the world (e.g. the drier margins of the Mediterranean Basin, California, the Sahel, parts of south and south-east Australia). They are generally more palatable and more nutritious during their active growing phase than most perennial species (Noy-Meir, 1992). They are dormant during long periods of drought and respond rapidly to the renewal of available soil moisture. Their main disadvantage for livestock and the environment is their poor quality when mature and their rapid disappearance during long, dry periods. Exposure of bare soil is a hazard that can aggravate wind erosion and site degradation on sensitive soils. The image of annual grassland as a penultimate degradation stage from the pristine climax vegetation has elicited disapproval from range management consultants, administrators and ecologists. Whereas in some cases annual species create an undesirable degraded pasture, in many others cases, they ensure a productive and usually sustainable grassland (e.g. Heady, 1960; van Keulen, 1975; Breman and de Wit, 1983; Breman and de Ridder, 1991).

Drastic transitions that reduce the forage value of the vegetation need not necessarily reduce the productivity or the biodiversity of the ecosystem. Such switches can be ruinous for livestock husbandry (Saravia Toledo, 1993) but sometimes the invading unpalatable species have other economic (or environmental) values. There is the example of the "Pilliga scrub" in Australia that was open parkland in 1830. Grazing and drought at the turn of the century favored the encroachment of white cypress pine (Callitris glaucophylla) which, after about 60 years, has become a sustainable source of timber (Walker, 1993). In less extreme cases the vegetation may change to one in which the resistant, unpalatable species have no obvious economic value, but do maintain the ecological integrity of the system by facilitating diverse biological activity, including that of small and large game, birds, bees, butterflies and other useful or attractive insects (Le Houérou, 1993b; Pieper, 1994).

Order and chance in grassland dynamics. The realization that in reality, dry grasslands are, as a rule, non-equilibrial systems subject to episodic, chance events (Noy-Meir, 1973) rather than to orderly, equilibrial change along a linear succession controlled by grazing pressure (Ellis and Swift, 1988; Westoby et al., 1989; Behnke and Scoones, 1993), has made it necessary to redefine range condition and degradation (West et al., 1994). By weakening the tight relationship between range condition and reversible successional stages (Pendleton, 1989; Smith, 1989; Wilson, 1989), the field has been opened up for definition of numerous 'states' with no clear indication of their status with regard to 'health' (Anon., 1994) or condition of the ecosystem. 'Reversibility', 'thresholds', 'hysteresis', 'states', 'transitions', 'opportunism' are terms of the new grassland paradigm that need to be examined in order to determine the limits of their validity and their implications for sustainability of arid and semi-arid grasslands. So, for instance:

- Reversibility in relation to arid grasslands is a relatively loose term because with constant change in a highly multi-dimensional system subject to complex dynamics and stochastic externalities, it is unlikely that it is ever strictly possible to return to any previous state. Nevertheless, there are 'domains of attraction' (May, 1989; Friedel, 1991) around which changes are constrained and within which changes can be regarded as 'reversible' and 'sustainable' (Briske and Silvertown, 1993; Laycock, 1994). Irreversibility involves crossing a threshold to another 'domain of attraction', characterized by a drastic change in vegetation composition and species longevity, with or without extreme substrate change.
- Transitions occur through time. Reversible transitions on a 50- to 100-year time scale are 'irreversible' on a 5- to 10-year time scale.
- State of the plant community on a site at a given point in time is defined by its species and site characteristics. It can be represented as a point in a multi-dimensional 'lumpy continuum'. Reduction of dimensionality by various principal component and ordination techniques can condense complexity but seldom does it reveal discrete entities, clearly separated by sharp thresholds. This is especially so when states are distinguished by quantitative differences in occurrence of a more or less fixed set of species (Wiegand et al., 1995). Common elements blur boundaries between groups of states (e.g. Friedel, 1991). 'States' are defined by objectives so that the definition of the state of a site may differ depending on whether the objective is higher biodiversity, conservation of endangered species, or production of livestock forage (Smith, 1989; Wilson, 1989).'States' that are relevant to grassland management must be defined by the objectives of management.

Within so open-ended a paradigm, sustainability could mean continuous adaptation in a continually changing context.

MARGINS FOR MANAGEMENT

Management servo-mechanisms. Ranchers and pastoralists living in arid zones have had to cope with wide fluctuations in forage availability by resorting to opportunistic management, 'tracking' the vegetation by nomadism, transhumance or variable herd size (Scoones, 1994b) and brinkmanship, all appropriate but hazardous tactics (Goldschmidt, 1979; Lancaster, 1981; Sandford, 1994). In pastoral societies, relatively unrestricted mobility has enabled foraging livestock to "chase protein across the landscape" (Croze and Gwynne, 1981) by exploiting habitat heterogeneity, including topographic and altitudinal variation, seasonal migration between dry and humid areas, like the transhumance between the dry Sahelian grasslands and the Niger delta (Breman and de Wit, 1983), and by grazing on crop residues. The livestock operator can move to other forage resources, increase the size of the grassland unit by acquisition of additional pasture, reduce animal numbers, improve product quality (Ivy et al., 1993), diversify income sources, or, in extremis, give up livestock husbandry, - temporarily or permanently (Ellis and Swift, 1988). The 'ebb and flow' of livestock and pastoralists on arid grasslands is the expression of what could be termed a biological and socio-economic 'servo-mechanism' whereby adjustments are continually being made to maintain the production system and to counter threats to biological and/or economic survival. Concern for the sustainability of arid grassland production derives from the fear that the servo-mechanisms can no longer function adequately in both pastoral and modern societies (e.g. Scoones, 1994b; Oliva et al., 1995).

Other management responses to severe deterioration of the grassland resource include:

- fire, to restore species balance or to improve palatability and nutritive value (e.g. Hodgkinson et al., 1984)
- rangeland rehabilitation measures (Noble et al., 1984)
- agro-technical interventions (in semi-arid regions - reseeding, fertilizer application, brush control or brush establishment, etc.)

On dry grasslands, technical interventions are constrained by risk of failure and high expense (Sandford, 1983). Changing attitudes to public lands may release funds for such measures where the need is widely recognized.

Where feasible, forage failure can be alleviated by supplementing livestock with exogenous feed inputs. This can then cause increase in animal numbers, sometimes with associated devastation of the grassland (Le Houérou, 1992; Narjisse, 1995). As a rule, such areas are not very far from urban centers. Improved infrastructure and transport in developing countries is bringing the pastoral population closer to alternative feed sources and convenient markets as well as to other sources of income and employment that buffer some of the adversity on arid grasslands (Shmueli, 1980; Lancaster, 1981).

Opportunistic or adaptive management has a large arsenal of responses to fluctuations in grassland conditions. Not always are these responses sufficient to ward off adversity, but continually changing conditions often provide new opportunities for recovery.

Additional and alternative land uses. The lure of the city, access to education and more diversified sources of income have created options that are more secure, more lucrative and often more challenging than what the pastoral life can offer. At the same time, alternative land uses for ecotourism, conservation, cultivation, urban and infrastructural development are encroaching on the grasslands (Table 1). However, infrastructural development and expansion of tourist and recreation facilities in arid regions do not necessarily spell the end of livestock production. They create new opportunities for diversification and for more viable livestock production systems, whether integrated with conservation and tourism or on separate areas (Table 2). The possibilities are many and, if anything, the number of stakeholders with vested interests in the dry grasslands will increase (Anon., 1994). There are those directly concerned with livestock production - bankers, stock dealers, equipment, material and feed suppliers, veterinary services. Urban communities become stakeholders when water quality from grazed watersheds conflicts with grazing. However, the stakeholder with increasing influence is the concerned public, interested not only in ecotourism and recreation, but also in biodiversity, habitat integrity, landscape aesthetics, pristine ecosystems, rare and endangered species (Anon., 1994). Some of these interests are compatible with livestock husbandry but in some cases, real and serious conflict of interest over land use may make separation inevitable (Havel, 1986) However, on arid grasslands, integration of diverse activities is often feasible and desirable (Table 2). Grazing is often necessary for survival of many species and to maintain the character of grasslands, especially those that are 'grazing induced ecosystems' (Perevolotsky, 1997).

Signals of distress and opportunity. Opportunistic management depends on the ability to detect 'opportunity' for improving system condition or preventing it from deteriorating 'irreversibly'. Signals can be emitted from the vegetation, the soil, the water, the animals, the secondary fauna, or the cash flow. They include early encroachment of undesirable species that are potentially able to dominate the grassland, imminent elimination of desirable species or vegetation structures, signs of accelerated erosion, excessive runoff, reduced vigor of desirable species, poorer condition or performance of animals in relation to standards for the enterprise, increasing unsustainable debt. The vast areas of arid and semi-arid grasslands make it difficult and expensive to monitor change and to identify signals (Wilson et al., 1984). Even in the USA, where special agencies in the Soil Conservation Service, Bureau of Land Management and the Forest Service have been set up to monitor rangeland conditions, records are regarded as inadequate to determine whether all is well on the range or whether ecological disaster is the emerging reality (Anon., 1994; West et al., 1994). Satellite imagery has been harnessed with some success to monitor range condition (e.g. Croze and Gwynne, 1981; Stafford Smith and Pickup, 1993), but on arid grasslands, ground truth is still necessary to confirm interpretation of rangeland condition from remotely sensed signals. Installation of standard monitoring services on a wide scale hardly seems likely because of the low priority of arid grasslands in national economies. Monitoring of 'ecosystem integrity' by agencies that do not have a wider interest in the system than just livestock husbandry may gain wider support when public concern is aroused (West et al., 1994). Grasslands are managed by pastoralists and ranchers who continually monitor their resources but who do not necessarily appreciate the longer term implications of their decisions. When producers were asked at the last IGC whether they should play a role in setting grassland research priorities, they answered, "No, a farmer's view of grassland production is too short term" (Foran, 1993). This puts the ball back into the research court.

Multiple-goal analysis. Analysis of alternative policies or management strategies is seldom cast in an objective format, partly because of the difficulty of defining quantitatively the structure and function of arid grassland ecosystems in terms significant to the main stakeholders, partly because of the lack of appropriate methodology in which all have confidence, and partly because of conflicting interests among stakeholders (Havel, 1986). Constructive dialogue is necessary for conflict resolution but difficult to achieve (Scoones, 1994b). More formal analyses of alternatives could help make the dialogue more transparent because it requires explicit definition of goals and their relationship to clearly defined system parameters. It can help estimate the tradeoffs in benefits and costs between participating stakeholders as a consequence of policies that impact differently on each of them. Interactive multiple-goal programming approaches in such a 'holistic' setting have been developed for application to analysis of land use policy (e.g. de Wit et al., 1988; Spharim et al., 1992). Interactive, participatory iteration can facilitate the evolution of more equitable management policies in a balanced multiple-use, multiple participant context.

CONCLUSIONS

Holes in holism. Current problems in arid zone grassland production require a more holistic view to encompass present day complexity (Foran, 1993). However, by widening the boundaries of the system, complexity is compounded. The whole is not only riddled with holes of ignorance and uncertainty but the perception of the whole depends on the perceiver. Still, if holism means considering the 'global', multiple-goal context of grassland management, then it certainly should be more widely adopted in determining research programs as well as management and development policy (Scoones, 1994b).

The elusive nature of arid grassland production. Whether measured as primary or secondary production, or as economic or environmental benefit, arid and semi-arid grassland production, even within a region, is a constantly changing quantity that can take virtually any value over a wide range between an upper potential value and a lower bound that, over the short term, can be less than zero when conditions are deteriorating. For sustainability to have any meaning under such dynamic conditions, it must be defined very broadly to include the wide range of responses open to the ecosystem, the producer and the community at large.

Arid grassland policy alternatives. Government policy can influence all stakeholders in arid grasslands either indirectly through taxation, veterinary or trade legislation, or directly by infrastructural development, sectoral subsidies, extension, technology transfer, implementation of regulations related to tenure, landuse, access, mobility, animal health, welfare etc. (Sandford, 1983; Scoones, 1994b). Policies will be based primarily on political considerations so that consideration of the interest of the producers is contingent on strengthening their political representation, especially in developing countries (Sylla, 1994).

The role of research. On arid and semi-arid grasslands where production is dependent on chance or uncontrollable circumstance rather than on manipulation, the objectives of applied research, while real, tend to be diffuse. They include: identification of tradeoffs between management goals in complex grassland systems; improvement of our understanding of the implications of intervention; development of ideas, indicators, and monitoring facilities that can improve capabilities for living with change; and promotion of awareness among politicians, administrators and the public, of the potential use and limitations of arid grassland.

Grazing is a heavy and pervasive disturbance on some arid grasslands, but compared to cultivation, fire, brush clearing, 'type conversion', deforestation, infrastructural development, mining and urban development in arid zones, it is a benign activity with far less devastating effects on the vegetation and habitats (Loiske, 1995; Tapson, 1993). However, sustainability of livestock production on these grasslands is being challenged by disruption of traditional systems in developing countries and by changing attitudes to land use in developed countries. Identification and diagnosis of problems and guidance for continuing use of the multiple resources of the grasslands will be needed by all stakeholders, especially the pastoralists and the ranchers whose livelihood depends on the productivity of the arid grasslands.

Adaptive sustainability of arid and semi-arid grassland production. Sustainability of livestock production on arid and semi-arid grasslands requires constant adaptation to change in range condition, to the 'ebb and flow' of opportunity and fortune (Sandford, 1983; de Wit and Seligman, 1992). Traditionally, this has been the implicit management paradigm on these grasslands (Ellis and Swift, 1988). Today it is being given more formal recognition by grassland science. Some grasslands are fragile and degrading, but many, if not most, are robust, persistent and productive. Production systems, however, depend not only on the ecological integrity of the grasslands, but also on the economic background, the cultural context, attitudes to land-use values, and the political environment. All these make livestock production on dry grasslands a continuing challenge (Sandford, 1994). Airplanes, internet, and satellite multi-channel TV will ease the isolation of distant regions so that some will prefer the solitude and challenge of the range to the stress and challenge of urban life. Even though other goals may become more important, the enormous forage resources of these grasslands remain a good reason to continue the development of various and novel exploitation systems based on both domestic and wild ruminants.

ACKNOWLEDGMENTS

We thank Dr. A. Perevolotsky, Mr. M. Guingold and Dr. E.D. Ungar (Department of Natural Resources, ARO - Volcani Center) for reviewing an earlier draft of this paper.

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Table 1
Some non-intensive options for utilization of the diverse resources on arid and semi-arid grasslands

Resources	Options for utilization*											
	Production					Recreation					Conservation	
	Ranching		Pastoral		Oth	Active		Passive				
	CR	FR	MP	TP	NP	HN	RV	AT	ET	CB	RG	RS
Vegetation												
- forage	X	X	X	X		X						
- browse	X	X	X	X		X						
- wood	?	X	X	X		?				?		
- specialties#					X	?		?		?	?	
- unique spp#									X		X	X
- biodiversity	X	X	X	X	X	?		?	X		X	X
Fauna												
- livestock	X	X	X	X				X				
- game	?	X	X	X		X		?	X	X	X	X
- wildlife@	?	?	?	X		?			X	?	X	X
- avifauna		?	?	?		X		?	X	?	X	X
- microfauna@				?	X						?	X
- biodiversity									X		X	X
Landscape												
- space						X	X		X	X		X
- habitat divers	X	X	X	X	X	X	X		X	X		X
- unique sites								?	X	X	X	X
Water												
- local	X	X	X	X	X	X					X	
- watershed	X	X	X	X							X	
- aquifer	X	X	X								X	

X Use depends on resource
? Use may be related to resource
Medicinal, spice, culinary, honey, spectacular, spp.
@ Non-game vertebrates and invertebrates

*Options for utilization

Production

- Ranching
  - CR .... Commercial
  - FR .... Family
- Pastoralism
  - MP .... 'Modern'
  - TP .... Traditional
- Other
  - NP .... Natural products

Recreation

- Active
  - HN .... Hunting
  - RV .... Recreational vehicles
- Passive
  - AT .... Agrotourism
  - ET .... Ecotourism
  - CB .... Camping, backpacking

Conservation

- RG .... By regulation
- RS .... Reserves

Table 2
A subjective estimate of the degree of compatibility or incompatibility between arid grassland uses

Use*	FR	MP	TP	NP	HN	RV	AT	ET	CB	RG	RS
CR	X	X	XX	X	X	X	X	X	X	X	XX
FR		X	X?	O	X	X	O	X	O	X	XX
MP			O	O	X	X	?	X	O	X	XX
TP				O	X	X	XX	O	O	X	X
NP					O	X	O	O	O	X	XX
HN						X	X	XX	X	X	X?
RV							X	XX	X	XX	XX
AT								O	O	O	XX
ET									O	O	O
CB										O	O
RG											O

* Legend for uses in Table 1.
O - compatible; X - partly compatible; XX - incompatible

Figure 1
Alternating alternative and mainstream phases in English agriculture during the past 600 years (after Thirsk, 1994).

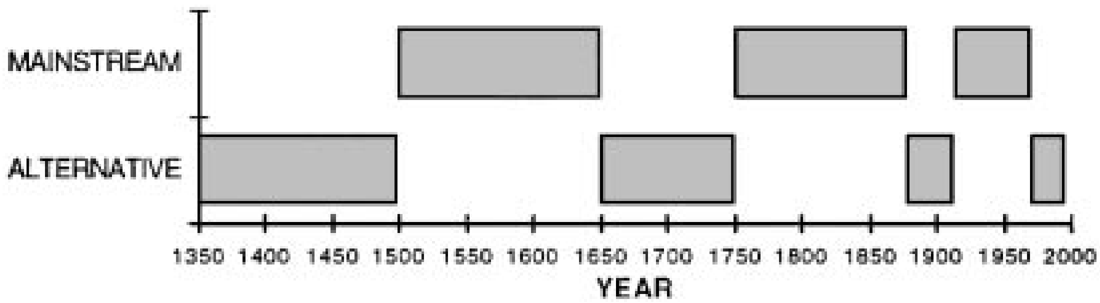

Figure 2
Arbitrary functions, like these pictured above, that are used to generalise the response of herbage production to rainfall should take into account the probable existence of a threshold of plant extinction, r_o. However imprecise the function or however variable the response above r_o, the values below r_o are all close to zero.

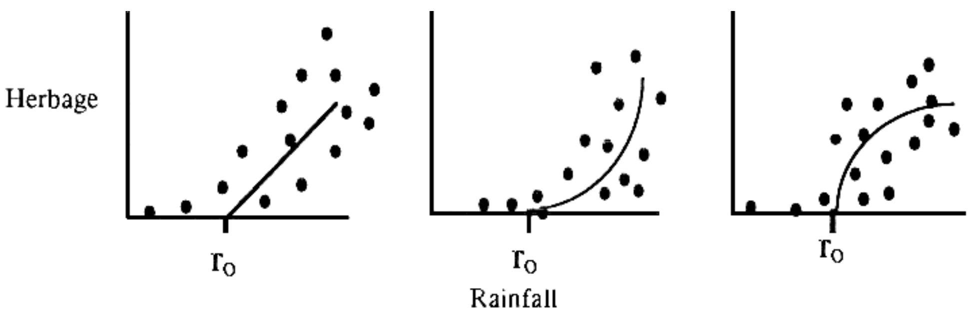

Figure 3
Grassland production in the Mediterranean and Sahelo-Sudanian zones (A - Le Houérou and Hoste, 1977) and on sandy soils in the north and south of the Gourma region, Mali (B - de Leeuw et al., 1993). In A, the rainfall thresholds calclulated from these data, r_o, are given (in mm) as x(Med) and x(Sah) for the Mediteranean and and Sudano-Sahelian zones respectively.

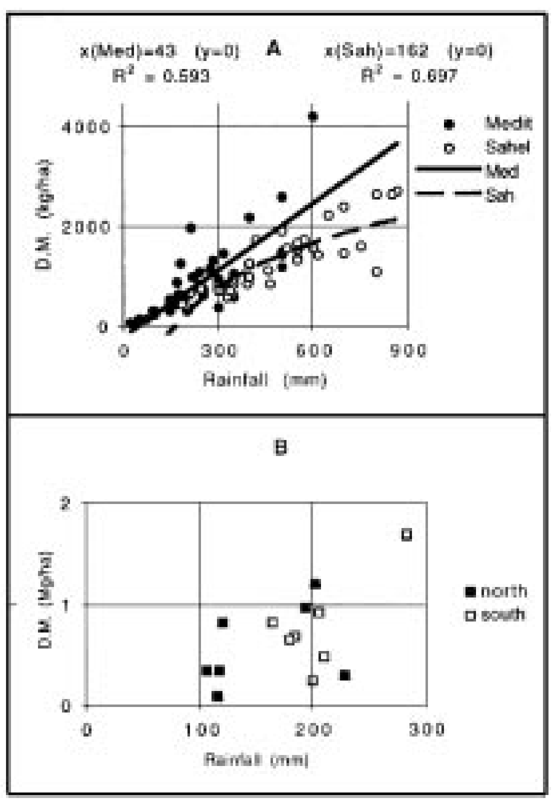

Figure 4

Trends since 1950 in numbers of cattle and wool-producing sheep in representative arid zone countries based on livestock estimates reported in FAO yearbooks (FAO, 1969, 1979, 1994)

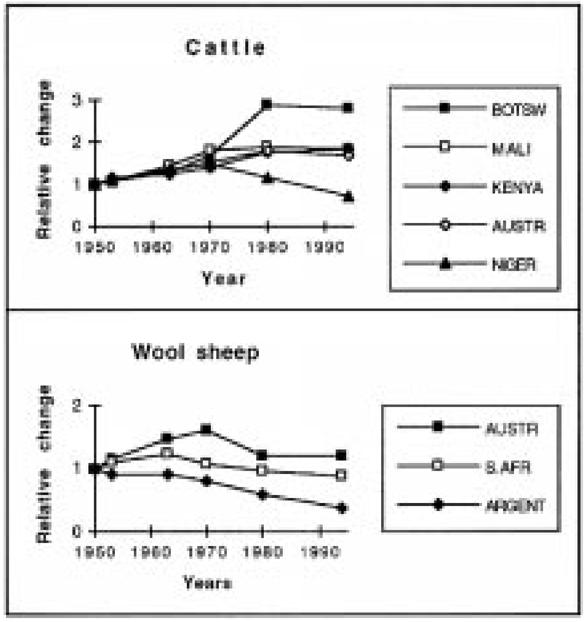

Figure 5

Trends since 1950 in numbers of sheep in some arid zone countries in Africa and Asia (FAO, 1969, 1979, 1994)