GRAZING MANAGEMENT IN THE TROPICS

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ABSTRACT

Objectives in tropical livestock enterprises are more varied than in most temperate situations. Only in enclosed or fixed area management systems are they generally similar. With communal grazing or nomadic systems, objectives are usually not to maximise profits from sales. Grazing management, other than through the control of stock numbers and animal species combination, is difficult to implement. In fixed area systems, stocking rate (SR) is the major factor influencing production/animal (P/A), production/ha (P/ha) and sustainability of the resource. Long-term profit maximisation from sale of animal products is likely to occur at less than half the SR at which animals just maintain weight. Sustainability issues should therefore be less of a problem where profit maximisation, rather than numbers of animals, is the objective. However, this is not always so. The slopes (b values) of the relation between SR and P/A vary greatly between pastures, indicating different susceptibility to increased SR. Compared with SR, stocking method (SM) has less influence on P/A and P/ha. Continuous grazing (CG) is an acceptable grazing management for most grasslands. Claims that some forms of multi-paddock grazing systems markedly improve P/ha have not been substantiated experimentally. A fuller understanding of the effects of defoliation on vigour, competitive ability, seed production and longevity of individual species may help define grazing strategies, based on ecological concepts such as the state and transition model, to restore degraded pastures or maintain productive ones. Such strategies need to be realistically tested. A major challenge is to produce evidence that conservative SRs can be economically and environmentally sustainable and to convince producers.

KEYWORDS

Stocking rate, stocking method, animal production, pasture management.

INTRODUCTION

Forage in the tropics is utilised in a wide variety of ways: cut and carry systems, where animals are penned and never choose their own feed; tethering on roadsides, under trees or in fields by day and in pens at night; grazing in the day only and in pens at night (as in many parts of Africa); grazing throughout the day and night as in Australia, USA, S. Africa and S. America. In one situation in Indonesia, animals are restricted by law from grazing - they have to be tethered or penned to prevent damage to crops (Piggin and Parera, 1985).

We define grazing management as the utilisation of a specific area of pasture by grazing animals to achieve specified objectives. Objectives could vary widely - from achieving a social status where the objective is to carry as many cattle as possible, to making as much profit as possible from the sale of animals or animal products. Increasingly, there is pressure to consider sustainability objectives which involve maintaining or improving the resource in terms of its production potential without adversely affecting other ecosystems or reducing biodiversity.

Achieving these objectives involves many factors other than grazing management. Inputs such as provision of water supplies, health care and genetic improvement of the livestock, burning, sowing of exotic species, application of fertilisers or irrigation and conservation of excess feed could all be involved together with socioeconomic factors. The vast majority of grazing animals in the tropics is, however, managed extensively on native pastures with limited inputs to intensify production. Dairying at high altitude, where the systems are more akin to temperate pastures, is an exception.

In this paper we outline the major grazing systems in the tropics; review the effects of stocking rate (SR) and stocking method (SM) on production/animal (P/A), production/ha (P/ha) and sustainability of the resource; discuss trends in the grazing management debate; relate grazing management to ecological concepts and briefly consider future challenges.

GRAZING SYSTEMS

Three fairly distinct grazing systems are recognised in the tropics (Jones et al., 1984).

Enclosed or fixed area management - practiced in Australia, parts of southern Africa and parts of the Americas. Under this system properties are well defined and fenced. Management is generally confined within this defined area.

Communal grazing - prevails in much of central and southern Africa, India and south-east Asia. Common lands grazed by the animals are usually associated with adjacent crop lands. Animals graze the communal grasslands in the growing season and cropping lands in the dry season. Availability of crop residues and crop by-products in the dry season enables high numbers of animals to be kept with corresponding high pressure on the communal grazing lands.

Nomadic/transhumance herding of animals is widespread in the semi-arid areas of Africa. This system is becoming increasingly restricted by population increase and associated cropping.

In all these systems there are three components of grazing management:

1. Number of animals using the grazing resource. When expressed as animals per unit area this is known as the stocking rate (SR).

2. How animals are allocated to the resource over time. This is the stocking method (SM). It can vary from being very simple - all the animals graze all the resource all the time; or very complex, involving many divisions of the resource into paddocks or strips which may be grazed sequentially and also by different classes of stock. In continuous grazing (CG) a paddock is basically stocked season or year long, not necessarily with a set number of animals. In rotational grazing (RG), animals are moved rotationally from paddock to paddock. The duration of grazing and spelling can be varied to give an infinite number of rotational grazing systems. In very large paddocks, common in the tropics, grazing distribution is an important element to be considered.

3. Composition of the grazing flocks or herds. These can be single or multiple species and consist of animals of the same or different sex and age.

Manipulation of these variables is more applicable to the fixed area management practiced in the more developed countries. It is far more difficult to vary grazing methods in either communal grazing or nomadic/transhumance systems.

GRAZING MANAGEMENT IN PASTORAL AND NOMADIC COMMUNITIES

While this neat separation of grazing management into three components is useful, they should not be visualised as separate from the farming system concerned, especially in pastoral or nomadic systems. Attempts to improve grazing management of these systems without consideration of their goals, motives, social structure use of cattle as capital, and other inter-related factors is fraught with danger (Goldschmidt, 1981). For example, the primary objective of these systems is continuance over the long-term and not profit. Furthermore, many pastoral systems have developed ways, overtime, of utilising their habitat so that they can recover after the inevitable disastrous drought (Hillel, 1991). However, there is a danger that, if the productivity of the grazing system is increased through habitat or management improvements in the short-term, the community and the resource will be less able to recover from the same severity of drought.

Thus, while many of the biological principles of grazing animal/ plant interactions discussed in this paper are relevant to pastoral/ nomadic systems, many of the management practices discussed will not be. However, the social implications of grazing management should not be overlooked in 'fixed-area' management (Heidschmidt and Walker, 1996).

STOCKING RATE EFFECTS

SR can be expressed in several ways. The expression in terms of animals per unit area is usually preferred (Shaw, 1970). On extensive range, usually with less than one animal/unit area, area per animal is more common. Throughout this paper we will express SR as animals/ ha. The animals need to be specified. Attempts have been made to standardise animal units (AU) so that comparisons of results across experiments and systems can be improved (Heady and Child, 1993; Roberts, 1980), especially when mixed animal populations are involved. However, despite the logic of using standardised units, these are not widely used. In rotational grazing (RG) systems, individual paddocks for specified periods will have a SR higher than that of the whole property. This is usually termed stocking density to avoid confusion with overall SR.

The relationship between SR and P/A has been widely studied and conflicting paradigms have co-existed for decades (Hart, 1993). All the main paradigms eventually show a decline in P/A as SR increases, though the pattern of decline varies (Figure 1). The linear relationship of Hart (1978) and Jones and Sandland (1974) are very similar and follow that proposed by Riewe (1961). For short term grazing periods, the Hart model with a clearly defined plateau in P/A at low SR is certainly valid and acknowledged by Jones and Sandland (1974). However, such a plateau is rarely found in published data for year-long P/A on tropical pastures.

Comprehensive relationships between SR and P/A for tropical pastures have been proposed by Jones (1981) and Rickert (1996). However, in most situations in the tropics, the area of interest is the portion of the curve where P/A declines with increasing SR. Accepting that the linear relationship P/A = a - b SR is a reasonable representation of the effect of increasing SR on P/A, it follows that the P/ha response to increasing SR is quadratic of the form P/ha = aSR - b SR^2 (Figure 2a). Therefore maximising P/A <u>and</u> P/ha at the same SR, which is predicted by the Petersen, Lucas, Mott (1965) model, cannot be achieved. Reduction in P/A has therefore to be accepted if high P/ha is to be achieved. Jones and Sandland (1974) predicted that, at a SR to maximise P/ha, the P/A would be about half of that at very low SR. The implications for grazing management to achieve given objectives for various classes of stock can be readily appreciated. There is no sharp peak in P/ha at any specific SR. Rather there is a range of SRs where P/ha varies little.

IMPLICATIONS FOR PROFITABILITY AND SUSTAINABILITY

This topic has been ably reviewed (Rickert, 1996). A major question is - where does the SR for maximum profitability lie in relation to the SR for maximum P/ha? The relationship between SR and profitability, unlike that between SR and P/A, is not linear. In most situations, variable costs increase with SR and so the SR for maximising profit will be lower than for maximum P/ha (Dankwerts and King, 1984; Heitschmidt and Walker, 1996). At this lower SR, quality of the livestock could be higher and so attract higher prices.

Ideally, SRs to achieve maximum profitability should also be sustainable. Where profit maximisation is not the objective and high animal numbers **is** an objective, it will be more difficult to achieve sustainability - more than twice as many animals can be carried at maintenance level than for maximum profitability. At this high SR, feed availability is markedly lower than at SRs for maximum profitability (Figure 2). Thus, it is surprising that system dynamics in African savannas are said to be affected more by abiotic factors such as rainfall than by biotic factors such as animal numbers (Ellis and Swift 1988; Abel 1993; Scoones 1993). Whenever the options of moving to new areas to relieve drought stress are reduced, as they continually are, then the SR on the resource must increasingly become the dominant factor, although interactions of SR x abiotic factors must occur.

High SRs are linked with low soil surface cover, low rainfall infiltration rates and increased erosion particularly where soil cover is <40% (McIvor et al., 1995). In fact, overgrazing is the most important cause of human induced soil degradation estimated at 679m ha worldwide (Oldeman et al., 1991). The major areas lie in developing countries of Africa (243 m ha), Asia (197 m ha) and S. America (68 m ha) and with 83 m ha in Australia.

We may well ask why this should be if SRs for maximising profit are lighter than those for maximum P/ha and more likely to be sustainable? In developing countries, with rapidly increasing human populations and their livestock in communal grazing systems ('the tragedy of the unmanaged commons') or under nomadic grazing, this is perhaps understandable. Why should it also occur in developed countries in the tropics such as Australia and Southern Africa?

There could be several reasons. The perception that heavy stocking rates are essential for maximising profit is still widespread in many countries. However, increased fixed costs - eg rental of land, or reduction in the sale price of animals can necessitate a <u>reduction</u> in SR to maximise profit, whereas most producers would intuitively believe they should increase SR to counter these forces (Workman and Fowler, 1986). Intervention of Governments, such as provision of subsidies for carrying fodder to droughted areas can also lead to higher stocking rates and pasture degradation. Similarly, high investment value of land compared with its productive value may lead to heavy stocking (Dankwerts and King 1984). Unfortunately, there are few data sets from long-term stocking-rate experiments in tropical environments that could be used to assess the relationship between SR, P/A, P/ha and economic or environmental sustainability.

Short-term experiments could give grossly misleading results since SR treatments are usually imposed on uniform, usually good, stands of pasture on all treatments. The carry-over effect of this at the high SRs delays the true impact of these grazing pressures and results in lower 'b' values in the relation between SR and P/A compared with values derived in later years (Roberts, 1980). Furthermore, short term experiments may not allow for the impact of drought periods to be expressed and often do not allow adequate time for the demographic changes involved in pasture degeneration (Jones et al., 1995). Calculated SR's for maximum P/ha and sustainability can then be over-estimated. Although theoretically a SR which is sustainable environmentally should also be more sustainable economically, there is little evidence to support this (Rickert, 1996). This information is vital; it is a sad reflection on pasture/animal research that this information is not available. If it can be convincingly shown that environmental sustainability is compatible with economic sustainability, then sustainable grazing practices will be much more readily adopted, particularly where profit is a major motivation. However, long term experiments or commercial experience may be necessary to prove this.

Other important factors which have exacerbated pasture degradation in Australia are the use of mineral supplements and better adapted *B. taurus* x *B. indicus* cattle. Both these factors have increased grazing pressure, through increased stocking rates, higher intakes and better survival.

The SR for highest profit and SRs that lead to pasture degradation may be closer in some enterprises than others. For example, increasing SRs often lead to the production of finer wool which has a price premium, whereas beef quality is often lower at higher SRs. In the sheep enterprise, therefore, the zone for highest profit may occur nearer to that for degradation (Rickert, 1996).

Rainfall fluctuations from year to year in the tropics can be higher than in temperate zones, especially in arid and semi-arid areas. This makes it more difficult to devise stocking strategies and grazing managements to cope with the variability. Lighter stocking rates reduce the risks of forage deficits and financial losses but only at the expense of higher returns in good seasons. Higher stocking rates pose the risk of high financial losses in poor years and are environmentally damaging. For these reasons, flexible stocking strategies may combine the benefits of each approach (Hatch et al., 1996). Certainly, in these drier environments, SR will need to be varied, but the SR and P/A relationships still hold. Some prominent graziers emphasise the importance of conservative stocking rates in general and of reducing stock numbers early in drought periods (Landsberg, 1993; Mann, 1993; Ivy et al., 1993)

In less extreme environments, a 'rule of thumb' to define a maximum sustainable stocking rate is that at which a critical level of utilisation is not exceeded in the majority of years (Rickert, 1996). This utilisation level would vary with soil fertility level and rainfall at the site. For example, in the eucalypt savanna area of northern Queensland, a suggested long-term sustainable stocking rate for continuously grazed adult steers was that which resulted in <30% utilisation of the pasture in 70% of years (Scanlan et al., 1994). Although not always applicable for practical management, the principle of utilising a set percentage of the measured or anticipated pasture growth is being promoted among graziers (Partridge, 1993).

In intensively managed ryegrass pastures in temperate areas, sward height is a useful tool for grazing management. This simple measure is based on a detailed understanding of pasture photosynthesis, growth and decay (Parsons et al., 1983). This approach could be useful in the wet tropics or more intensively managed systems. However, this concept will be less useful in semi-arid tropical regions where rainfall is more variable, pastures have a greater mixture of species, patch grazing occurs, scope for controlling stock numbers is limited and where it is necessary to carry over feed into the dry season for forage or fuel.

STOCKING METHODS

The previous section has emphasised the overwhelming influence of SR on animal production (e.g. Jones et al., 1995) and resource condition (e.g. McIvor et al., 1995). As SR increases, solar energy capture and assimilation efficiencies decrease but harvest efficiency by grazing animals increases. Herein lies the fundamental physiological dilemma - it is not possible to maximise solar energy capture, harvest efficiency and assimilation efficiency simultaneously (Heitschmidt, 1993). Can different forms of SM over-ride the responses to SR we have described? The experimental evidence is that they cannot.

From the reviews assessing various grazing methods from the wet tropics to the semi-arid sub-tropics ('t Mannetje et al., 1976; Humphreys, 1991; O'Reagain and Turner, 1992), the conclusions drawn by Willoughby (1970) from experiments mainly on temperate and Mediterranean pastures, still seem relevant: *'Firstly, continuous grazing is a practicable system of grassland utilisation and is capable of high animal production. Secondly, any other system of pasture management requires that the stock be restricted for a time to less than the whole food supply available and thus introduces the risk of current animal production being depressed. For a management system to be superior to continuous grazing, subsequent access to the previously protected area or material must more than compensate for this prior depression'.*

Continuous grazing does not mean absence of paddocks on properties. Paddocks based on pasture type, soil differences or pastures for various classes of stock may still be necessary. Furthermore, the SR in each may be different to match the paddock differences or to meet specific production requirements and could vary over time. Neither does CG mean that plants are defoliated continuously since grass tillers under this system may be grazed as infrequently as in a rotational system (Gammon and Roberts, 1978). Although systematic rotational grazing is not common in tropical Australia, paddocks often have some long rotation or spelling mixed in with continuous grazing - although this is usually done to meet feed requirements for animals and not specifically for the benefit of the pasture.

With tropical systems dominated by lower quality C4 grasses, protection from grazing could result in lower quality associated with increasing maturity with possible adverse effects on animal production. Studies where paddocks were burnt, then closed to grazing after the break of the wet season, even for a few weeks, to prevent overgrazing of new growth and to enable a build-up of LAI, have shown dramatic depressions in animal daily LWG compared with the gains from animals continuously grazing the same pastures without the specified rest (Barnes and Dempsey, 1992).

It is interesting that the historical approaches taken to research on SM have differed so greatly between Australia and S. Africa. The earlier stress on SM in S. Africa almost implied that if the correct SM could be identified it would override stocking intensity or SR effects (Skovlin, 1987; O'Reagain and Turner, 1992; Kirkman and Moore, 1995). There was an explicit assumption that RG must be better than CG. Since the possible combinations of rest and grazing period are infinite with RG, a wide range of recommendations was made for multi-paddock grazing some of which appeared to be in conflict. The high utilisation grazing (HUG) system emphasised complete utilisation of herbage on offer, whereas with high performance grazing (HPG) the emphasis was on lenient utilisation of preferred species (Kirkman and Moore, 1995).

One publicised and controversial multipaddock (up to 30 or more) system is short-duration grazing (SDG) and its further development as time-controlled grazing (TCG) (Savory, 1978, 1983). Claims of doubling the normally accepted SR by using these methods have not been verified experimentally (Skovlin, 1987; Heitschmidt et al., 1987; Jones, R.M., 1993). It is not clear how intensive subdivision could greatly increase the biomass production in many tropical environments, particularly where there is usually only a short period of active growth.

Preconceived ideas about grazing management can be held despite inconclusive or negative experimental results (O'Reagain and Turner 1992; Barnes 1992). The concerns raised in these two reviews may well have been appreciated earlier by producers. For example, there was little adoption of controlled selective grazing in South Africa (Düvel and Scholtz, 1992). Despite the absence to date of any demonstrated advantage of TCG, in terms of higher productivity from controlled experiments, there is increasing interest by graziers in TCG (McCosker, 1995). Furthermore, production increases are claimed by users of the method, though these are often from comparisons with production achieved by SMs used earlier (McCosker, 1995).

In the Australian context, the historical emphasis has been placed on the major effect of SR and the use of CG (Willoughby, 1970; 't Mannetje et al., 1976; Humphreys, 1991; Rickert, 1996). However, some species persist poorly under continuous grazing. If the legume is a key to the production system, then loss of the legume will inevitably lead to lower productivity. Legumes which tolerate or thrive under CG are clearly more acceptable to farmers and graziers. However, if modified grazing management systems, based on demographic understanding of legume persistence, aid persistence (Jones and Carter, 1989), then the likelihood of adoption would depend on the benefits. Lucerne (*Medicago sativa*), is a classic example of a legume requiring specific SM for persistence and productivity (Leach, 1983).

STOCKING RATE AND STOCKING METHOD INTERACTIONS

The potential advantage of RG over CG may well be greatest at high SR. At this level of stocking, rationing the animals in a rotation system, as in New Zealand with dairy pastures (Bryant, 1993), could well enable the saved pasture to produce at a higher level at a later date or even enable a vital component to survive. However, even at high SRs the advantages of RG are frequently small or non-existent (Bransby, 1993). In rangeland systems, where SRs are low, the advantages of RG may occur at a SR which is above that for maximum P/ha. There would then be no point in changing to RG since the easier option is to reduce the SR and reap the benefit.

In the more variable environments of the drier tropics, where high utilisation rates lead to pasture degradation, conservative SRs would be recommended and at such SRs any benefit of RG on animal production is likely to be small.

TRENDS IN THE GRAZING MANAGEMENT DEBATE

There is now increasing consensus that SR is the dominant variable in grazing management and that much of the pasture degradation in the tropics is associated with SRs that are too high.

There is also an increasing awareness of the value of strategic rest periods as a management tool to restore plant vigour and/or to increase seed production of desirable species, particularly after stresses of drought and overgrazing (Danckwerts and Stuart-Hill, 1988). Such rests need to have specific objectives and be based more firmly on solid data rather than on only theoretical principles. Deferred grazing management of spring-burned sourveld to increase LAI, improve storage carbohydrate and total yields should theoretically have improved sheep production and maintained palatable grasses, yet the opposite occurred (Barnes and Dempsey, 1992). Their results indicated a "drastic revision of current recommendations" of management for sourveld.

A simpler management system to optimise utilisation of the veld burned in spring and which emphasises long-term rest has been proposed (Kirkman and Moore, 1995). The principle, based on the known beneficial effect of season-long rest on the productivity of *Themeda triandra* and *Tristachya leucothrix* (Peddie et al., 1995) appears sound but no data are provided to evaluate the system proposed. Where pastures have been degraded by overgrazing and soil seed reserves of key species are low, then some form of rest for seed set may be vital if seedling recruitment is important for long term persistence (Campbell et al., 1996). Tropical tufted native grasses generally have small soil seed reserves as a result of short longevity in soil and generally low seed production (McIvor and Gardener, 1991), which is further reduced under high grazing pressure (McIvor et al., 1996). High grazing pressure will also reduce herbage biomass and so prevent or reduce the ability to burn. Burning can help to control woody plants and can favour dominance by preferred species such as *Themeda triandra* and *Heteropogon contortus*. Burning can also alleviate patch grazing which can be a feature of extensive management systems (Andrew, 1986).

Orr and Paton (1993) demonstrated how a mixed pasture of speargrass (*Heteropogon contortus*) and wiregrass (*Aristida* spp.) can be improved by a management package involving spelling and burning. This involves light grazing over summer/early autumn to build up a fuel load and allow speargrass to seed, followed by spring burning, which reduces the vigour of wiregrass and enhances germination of speargrass, followed by light grazing/spelling to reduce or avoid selective grazing of the new speargrass growth following the fire and early season rain. However, it should be pointed out that unless the SR which induced the adverse changes is subsequently reduced, the problem is likely to recur.

Where there are differences in the seasonal growth patterns of desirable and undesirable species, there may be opportunity to increase the grazing pressure on actively growing undesirable species to reduce their proportion in the pasture (Lodge and Whalley, 1985). It may be that seasonal rotational grazing for specific targeted purposes can be advantageous, but this is different from rotational grazing as a year-long fixed system.

It is interesting that the historically different approaches to grazing management in South Africa and Australia, which have been previously described, are now drawing closer together. The key emphasis is on stocking rate, while recognising strategic seasonal spelling or grazing as a way of manipulating pasture composition.

These management practices may require more subdivision of paddocks and/or provision of watering points. Such inputs can reduce localised overgrazing and make it easier for management interventions such as resting, but there is a cost involved.

MIXED ANIMAL SPECIES GRAZING

When the grazing resource contains plant types with differing height, relative palatability and reaction to defoliation, utilisation could be improved by using a variety of grazers and browsers. The savannas of Africa are a classic example - not only do different herbivores use different species, but some prepare certain grasses for subsequent use by others (Owen-Smith and Cumming, 1993).

The nearest approach to this natural system is used by the traditional nomadic pastoralists. Here camels, cattle, sheep, goats and donkeys are used to utilise the resource and to provide a stable supply of many animal products, especially milk and blood, to sustain the associated human population (Owen-Smith and Cumming, 1993). In these arid areas, with very limited infrastructure, fluctuating climate and heterogeneous vegetation patterns, this is probably the most efficient way of using the resource. Studies to assess the most efficient mix would be almost impossible to define and would remain site specific.

In semi-arid and more mesic environments, cattle, sheep and goats have been used and, more recently, game animals have been added to supplement income of ranchers in southern Africa. Management strategies for these cattle/game ranches would be more complex than simpler systems but no practical recommendations have been developed (Pauw and Peel, 1993). Although woody plant production may match that of the grass layer, the productivity of browsers in natural ecosystems is less than that of grazers. Thus, a large fraction of the primary production from these woody species is not effectively utilised (Owen-Smith, 1993).

It is generally accepted that sheep have a greater potential for range degradation than cattle or goats and that mixed stocking with cattle can alleviate this (O'Reagain and Turner, 1992). Sheep performance in mixtures tends to increase as the proportion of cattle increases, whereas performance of cattle has been mainly affected by the SR of the cattle (Hardy and Tainton, 1995). Their work also showed that mixed species grazing only increased P/ha in the driest year of the four year study.

In S. Africa, goats have a much higher impact on browse than do cattle, and, conversely, less effect on grasses than do sheep or cattle. However, clear benefits from mixed species grazing on total animal production cannot be claimed because of flawed experimental design and the limited ecosystem range of the studies (O'Reagain and Turner, 1992). Interactions of species combination and veld type will occur. In practice, the economics of the various enterprises could be the major driving force for stocking policies.

LINKING GRAZING MANAGEMENT WITH ECOLOGICAL CONCEPTS

In recent years, there has been increased interest in ecological changes in rangelands and pastures. Alternatives to Clementsian succession include the "state and transition" model (Westoby et al., 1989). Put simply, in this model pastures are viewed as being in a series of states which are user-defined. The one paddock may have areas in different states, and the proportion of these states will vary with time. The factors affecting the transitions between these states can then be defined using available knowledge and/or after further experimentation. In some cases transitions may be linked with climatic variation, such as where recovery through seedling recruitment only occurs following sustained good soil moisture. However, attention to 'transition' events should be balanced with the cumulative effects of long-term management (Watson et al., 1996). The key biotic factors will usually be stocking rate, strategic spelling and burning, followed possibly by the introduction of other grasses and legumes and/or fertiliser into the system. Knowledge of the abiotic and biotic factors which affect transitional stages enables guidelines to be drawn up which can help to avoid and even reverse degradation.

As a pasture degrades, and there are less plants and seeds of desired species, possibly linked with a decline in soil physical conditions, it will require longer periods of appropriate management or greater intervention for recovery to occur (Jones, 1992) and hence will be more costly.

In temperate Australia, Kemp et al. (1996) have advocated the concept of a pasture management envelope, which evolved from work on tropical pastures by Spain et al. (1985). Management guidelines are drawn up to keep the pasture within certain boundaries of botanical composition. The guidelines may involve spelling or grazing at certain times of the year, stocking rates, herbicide application and fertiliser. This approach, unlike the state-and-transition, is based more on agronomic intervention.

FUTURE RESEARCH AND PRACTICAL CONSIDERATIONS

We have previously highlighted the problems in improving grazing management in communal or nomadic grazing systems. However, there are also major problems with improving guidelines for fixed area management. We still have an inadequate understanding of many areas of pasture science, especially in the temporal and spatial aspects of botanical change. Studies are still needed at the individual plant level on the effect of defoliation and spelling on growth, tiller dynamics, demography etc - and linking this in with studies of what animals are eating. As far as possible these studies should be carried out within a grazing "trial". The "trial" need not be a replicated experiment, but could be based on commercial paddocks run with contrasting SRs or management systems, such as TCG, provided that there are adequate back-up paddock scale pasture and animal measurements. These studies should be increasingly done in a process-oriented modelling approach. They will be used to develop management strategies, such as strategic spelling, burning and heavy grazing, rather than to develop formalised RG systems. To detect trends in pasture condition, more emphasis needs to be placed on small and large scale spatial variation and not just on mean values within a paddock. These detailed studies should be within the context of an ecological concept such as "state and transition".

Other problems relate to putting this improved understanding to practical use. Firstly, there are difficulties in relating small scale experimentation to the property level where there are animals of different ages and sex (or species) and greater spatial variability in pastures, feeding systems and animal production objectives within and between different commercial enterprises. Secondly, there are the problems of expressing ecological concepts, such as "thresholds" and "state and transition" in practical and financial terms in a way that is appropriate to producers (Brown, 1994). This cannot be achieved without interaction with interested ranchers/graziers who will become increasingly vital partners in improving links between rangeland science and management. Modelling will have an increasing role to play in rangeland science, whereas counterpart decision support systems will have an increasingly important role in rangeland management.

In northern Australia, decision support systems are being developed to appraise sustainability in grazing management systems (Bellamy et al., 1996). Such approaches, however, require considerable input data and grazier experience. Once developed and verified, however, decision support systems can be used on individual paddocks on properties to assess responses to changed inputs such as SR, water supplies, fire etc., in terms of animal production, estimated gross margins and risk to the resource in terms of botanical change and soil erosion. One interactive decision support tool being developed - Landassess DSS - promotes learning through participation in its development and its interactive easy-to-use nature. This permits the user to explore resource use problems so as to foster adaptive and flexible approaches to grazing management decision making (Bellamy et al., 1996).

Better rainfall prediction, e.g., use of the Southern Oscillation Index, could greatly aid decision making relating to SR (Heitschmidt and Walker, 1996). The impact may not be as great as with cropping. For example, in wet/dry environments, de-stocking strategy is often made in autumn at the end of the wet season when the grazier already knows what the feed supply is for the dry season (Partridge, 1993). However, for a grazier planning a spring burn, with the loss of stand-over feed, then the prediction concerning likely spring rain could aid decision making (Hammer et al., 1991).

In conclusion, we reiterate that the dominant factor in grazing management is the SR. The various forms of management discussed above have related to situations where the resource has been over-utilised. Even if restoration is achieved by appropriate management inputs, the problem will recur unless a sustainable SR is used. In most tropical areas, with large variations in rainfall from year to year, this rate can never be constant. Conservative SRs will reduce the need to make frequent changes, reduce year to year variation in P/ha, improve P/A and enable flexible management options such as the use of fire to control woody-weeds or access to a wider range of markets. A major challenge is to convince producers that such management is both economic and sustainable.

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Figure 1
Proposed relationships between stocking rate and liveweight gain per animal (Hart, 1978)

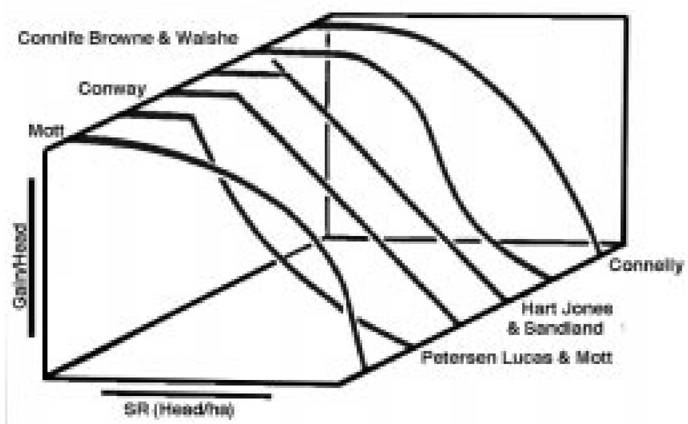

Figure 2(a)
Animal response to increasing stocking rate (SR) on a tropical native pasture, based on data from Jones, R.J. 1993.

P/A production/animal (kg) - P/A = 150 - 150 SR
P/A production/ha (kg) P/ha = 150 SR - 150 SR^2

$a/2$ = P/A at maximum P/ha
$-a/2b$ = SR for maximum P/ha
$-a^2/4b$ = maximum P/ha
♦ ∅ = zone for maximum profitability

Figure 2(b)
Pasture response to increasing SR expressed as feed availability/animal.

(---) $y = 4.1/SR$ based on the assumption that pasture production remains constant across SRs at 4.1t/ha

(—) $y = 47.22 \exp(-4.37SR)$ derived from the experimental data of feed availability at the end of the wet season (Jones, R.J. 1993).