Grasslands for Production and the Environment

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Grasslands[1] for production and the environment

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Key points

1. To manage grasslands for production and enhanced environmental values requires a redefinition of the frameworks within which management decisions are made, and a tailoring of practices to suit the ways that farmers operate.
2. Improving the perenniality and permanence of grasslands usually leads to better environmental and production outcomes.
3. There is a case for a more conservative approach to utilising grasslands in order to sustain the functioning of local ecosystems and to improve water quality, nutrient and energy cycling and biodiversity.
4. A landscape rather than paddock focus is more appropriate for meeting current grassland management objectives. Grasslands can be triaged to better focus R&D and management, though this could challenge society's preferences for products from more environmentally friendly ecosystems.
5. There is a need to find payment and/or market systems that mean environmental values are enhanced and farm income does not suffer.

Keywords: ecosystems, landscape, water, nutrients, biodiversity

Introduction

Grasslands[4] occupy large areas of the world's 117m km^2 of vegetated lands and provide forage for over 1800m livestock units (World Resources Institute, 2000), and wildlife. Grasslands are a major natural resource utilised for the production of food, fibre, fuel and medicines, and are critical for maintaining a favourable global environment. Today however, human populations are exerting such pressure on grassland resources that it is not possible to continue to simply maximise production as in the past. The challenge is to replenish resources depleted by production and reduce soil losses and vegetation degradation through a better understanding of the multi-functionality of grassland, to improve the ecosystem services upon which all living organisms rely and to enhance environmental values.

The objective of this paper is to discuss ways of responding to this challenge. What levels of utilisation from grasslands enable the maintenance or enhancement of the environmental values of grasslands? What are the opportunities for advances when much of the world's grasslands are overgrazed? Overgrazing/over-utilisation arguably applies where herbivore consumption rates exceed growth and, or recovery rates of desirable plant species and the grassland ecosystem function is impaired/degraded, often necessitating reseeding, or resulting in declining productivity over time, both of which reduce environmental values. What strategies are needed to resolve how best to satisfy production and environment goals? Are these problems technical or social? These dilemmas are complex because grasslands are productive natural resources and part of the environment that interacts with other

[1] In this paper the term 'grasslands' includes all those forage systems used by grazing livestock.

environmental processes e.g. climate change. Ultimately a way has to be found to utilise these important resources in a sustainable manner.

This paper considers both natural and sown grasslands. Emphasis is placed on general principles that underpin the development of grassland/livestock systems that are productive and environmentally sustainable. The paper is written from a farm-centred environmental perspective, looking back at grazing livestock systems to see what may need to change in order for grasslands to remain productive and to enhance the environment. For many issues there are as yet no optimal solutions. A starting point in this discussion is to first consider the services grasslands provide and then the framework within which farmers operate.

Grassland services

From man's perspective, the primary services from grasslands are the provision of food, fibre, fuel and medicines. Secondary services are the biodiversity of animals and plants needed to maintain nutrient, water and energy flows and the functionality of ecosystems. Additional services emerging as crucial in the 21st century are the role of grasslands in maintaining air quality, as carbon sinks, supporting pollinating and symbiotic organisms and other processes that maintain or repair ecosystems and landscapes. Unfortunately much of the work through the last century concentrated upon looking at grasslands as a production system rather than as an ecosystem and the services that grasslands provide were often ignored. Where productivity must be sustained over the long-term, the key issue is now how best to use grassland resources without causing deleterious effects to the environment, or decreasing incomes. To achieve this requires more integrated thinking about the processes operative in grassland ecosystems. Decision-making typically devolves onto farmers, so what influences them?

Do farmers aim to maximise product or profit?

The management of productive grasslands and of environmental impacts is influenced by the attitudes of farmers. Management has been treated as a simple technical issue, but the reality is that farming is done in a social context and profit is only one goal. Farmers often seek maximum productivity even if it is not profitable e.g. they want to maximise the number of animals per ha (as a measure of wealth) or the size of their animals (for show) or the total animal product per ha (almost irrespective of cost). The focus on animal performance can result in high grazing pressures and the need to continually resow grasslands. Vanclay (2004), proposes 27 principles that govern farmer behaviour; a subset relevant to this paper is:

- 'It is hard to be green when you are in the red', environmental management costs money.
- 'Doing the right thing' is a strong motivational factor; what is 'right' is a social construct.
- Farmers don't distinguish environmental issues from other farm management issues, they are all part of managing the farm.
- Sustainability means staying on the farm; the concept of sustainability often has a strong social component – passing on the farm to the next generation is a central issue.
- Non-adoption of 'good' practices may reflect the fact that past recommendations were not good. Can we guarantee that new recommendations will work any better?
- Farmers construct their own knowledge; practices need to be tailored to their frameworks.
- Farmers need to feel valued, particularly if society wants them to adopt more sustainable practices that may not make more money.

Applying these principles to improve recommendations for grassland management is a difficult task. They illustrate the need to consider the social context within which farming occurs and the ways that managing for the environment and production need to align.

Environment and society

The general importance of the environment in developed countries is evident in surveys. In Australia, members of the public rank the environment third behind family and friends as an issue of importance, ahead of leisure (which includes sport), service to others, work, religion or politics (Young, 2003). The general picture is that the public is concerned; they want something done, they are willing to pay for environmental management and they are concerned about agriculture, but less so than with other sectors of the economy cf. government and manufacturing industry. This suggests that agriculture has societal support to develop and implement more environmentally friendly policies. Similar attitudes would apply in Europe, where this is reflected in the policies of the European Union and the shift in the Common Agricultural Policy towards environmental management (Hall *et al*., 2004). However given that farmers do not necessarily distinguish between environment and farm issues (Vanclay, 2004), better environmental practices on farms need to be developed as part of production systems.

Productivity, profits and the environment

The need to maintain productivity, profitability and the environment is becoming the major interaction that farmers seek to resolve. Arguably environmental risks and costs increase with intensification, and the level of disturbance and utilisation of grasslands, leading to loss of resources and increasing costs of replacing nutrients and species and in managing the soil water balance and nutrient runoff. Exceptions to these generalisations do occur e.g. the intensively grazed, well-adapted *Lolium perenne* (perennial ryegrass) and *Trifolium repens* (white clover) pastures of New Zealand.

High utilisation rates and levels of productivity may not always be the most profitable. This is illustrated with the relative economics of sheep for wool production on grasslands in central NSW, using a gross-margin model (Vere *et al*., 1993). A comparison was done between resowing a degraded pasture with introduced species (*Phalaris* spp. and *Trifolium subterranean* (subterranean clover), or fertilising and managing the grassland (upgraded) back to a more productive state and stocking conservatively (Figure 1), (Michalk *et al*., 2003b).

In each case it was assumed that maximum stocking rates were delayed until year three in order to optimise the proportion of perennial grasses and improve the likely longevity of the pasture (Michalk *et al*., 2003b). The alternate pathway shown may be more typical of patterns on farms in the region, where few farmers have sown pastures in recent years (Reeve *et al*., 2000). The gross margin analysis of these pathways over the ten-year period for a range of conditions typical of the region (Figure 2) demonstrated that there was little difference in the net profitability of the two main pathways until higher stocking rates were attained.

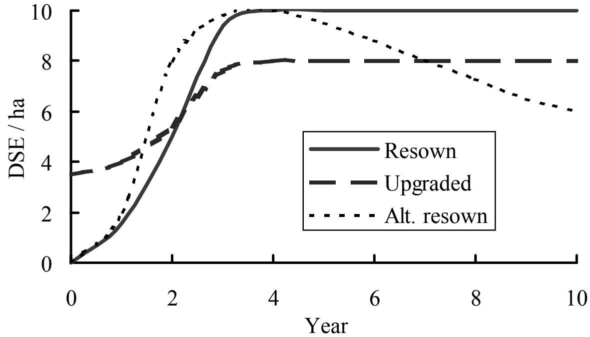

Figure 1 Modelled patterns in stocking rates (DSE: dry sheep equivalents) for grasslands managed to a more productive state (upgraded) or resown. The alternative resown pattern may be more typical of the region. Data are for an average area in central NSW (D.R. Kemp, *unpublished*)

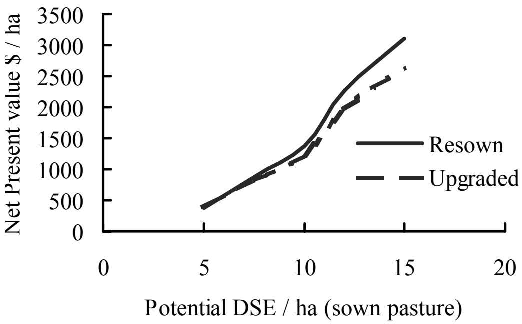

Figure 2 Net present value of alternative grassland management strategies over a ten-year period (D.R. Kemp, *unpublished data*). The 'upgraded' grassland is stocked at 80% of the sown

However, if the alternative (and more common scenario) is considered, i.e. that productivity in the region tends to decline over time (Figure 1; alternative resown pathway), the economics are worse (data not shown). This leads to the general conclusion that the most appropriate pathways for development and improved environmental outcomes arise from (conservative) grazing management - designed to retain the perennial species that are often lost, as opposed to resowing (Dowling *et al.*, 2001). The key point is that focus needs to be on net farm profits over the long-term rather than physical output or gross income. Much of the literature seems to ignore these criteria.

Revisiting concepts for productive versus sustainable grassland systems

There are often two general views of farming systems. The **first** view is that a 'factory' approach is sufficient where resources are put in one end of a pipe and products extracted at the other. In the 19th century J. von Liebig developed the concept of the 'law of the minimum' i.e. one factor is usually limiting production at any one point in space and, or time. That 'law' has helped develop the 'factory' view, but is it conceptually useful for more sustainable systems? In this mindset the focus is often only on a limited number of components, with some consideration of efficiencies, but no solutions for unplanned or adverse environmental effects. Limiting factors are applied to excess and any 'leakage' is seen only as inefficiency in primary production. Nitrate in water supplies can be seen as a legacy of this view.

The related concept of 'grasslands as crops' - developed from the early work of Stapledon, proved an excellent stimulus to better management of grasslands, but is it still useful? The crop analogy has merit for good husbandry, but as most crops aim to be monocultures, it conflicts with the reality of many types of grassland. Perennial grass and nitrogen fertiliser systems are still important in many regions, but many of those systems now aim to incorporate legumes to deliver better environmental outcomes, and to use the grassland phase to restore soil resources. If grasslands are treated as crops, does this then encourage over-use of resources and poorer environmental outcomes?

A **second** view of farming systems (coming more from managing natural grasslands) is of an ecosystem model where it is acknowledged that the system is sustained by maintaining species and the cycling of water, nutrient and energy flows. In this scenario products are harvested from ecosystems, it is acknowledged that the internal flows of energy and nutrients greatly exceed the amount harvested, and that the ecosystem needs to be maintained in order to sustain production. An ecosystem view aims to cycle nutrients internally and minimise leakage as much as possible for more judiciously applied inputs. A focus on overcoming single limiting factors is then inappropriate as this can distort the ecosystem leading to more chaotic behaviour. This approach fosters a more conservative, optimising net profit strategy.

A switch from a 'factory' to 'ecosystem' view of farming has implications. A key consideration is that within an ecosystem it would be impractical to manage each component to an optimum. Around the optimum there are a range of values that do not result in great losses in productivity, or ecosystem function; hence managing within a range is acceptable (Kemp, 1991) e.g. animal gain/ha. Farmers can manage more successfully over a range than continually chasing optimum or maximum values, thus actions only need to be initiated when near the limit of that range, rather than continuously.

Linkages between the environment and production

The close natural linkages between grazing, grassland productivity and gross environmental effects are well known e.g. normal seasonal cycles, the extremes of droughts and floods; but more subtle effects and how the resource base is sustained are less well known. Grazing can have significant negative effects on the soil water balance, depending upon the intensity of grazing, the residual herbage mass and the proportion of bare ground. Surface runoff, nutrient losses and reduced infiltration rates can increase in grazed paddocks (Elliott & Carlson, 2004). More conservative grazing strategies e.g. 10-20% below average, can increase the content of perennial grasses, reduce runoff, increase water transpired (reducing salinity and acidity risks) and reduce the need to resow (Michalk *et al*., 2003b). These components may have been influenced more by the standing herbage mass than directly by grassland growth rates or livestock productivity. The challenge for farmers is to determine the grazing pressure where adverse environmental impacts are low, yet productivity is satisfactory (Figure 1). These interactions will be considered from an ecosystem perspective in terms of the management of water, nutrient and energy flows, and the diversity of species required to sustain the ecosystem.

Managing water with grasslands

Sustaining clean and safe drinking water and irrigation supplies to meet the needs of the global population is a major issue for the 21st century. Water demands already exceed supplies in more than 80 countries with 40% of the world's population (Swain 2001). Grasslands are vitally important for the provision of water for agriculture, industry and domestic use.

The way that grasslands are managed can have major impacts on the water cycle, ecosystem function and on production. In Australia solutions to these problems lie in increasing the perenniality of plants in the landscape (Singh *et al*., 2003). Perennial-dominated grasslands fulfil two roles in water management – they efficiently utilise soil water due to deeper root systems and longer growing seasons than annual species, and they can protect the soil surface from soil and nutrient loss, particularly during high intensity short-duration storms. Unfortunately there is often a decline in the perennial component in grasslands resulting in more variable production over time, higher incidence of weed invasions, soil acidification, acute soil erosion and increasing salinity.

Harvesting water

Clean runoff and aquifer recharge from grassland catchments is crucial to maintaining water supplies for agricultural, industrial, domestic and environmental use, food security and for the progression of many societies beyond subsistence (van Wesemael *et al*., 1998; Raju 1998). Grassland management practices can vary the proportion of surface runoff to aquifer recharge (Bergkamp, 1998). This was evidenced in the recent Australian drought where over-grazing was controlled and less water (from the limited rain that did fall) flowed into dams and rivers. Maintaining herbage mass > 2 tDM/ha effectively controls runoff (Packer *et al*., 2003). Excessive clearing and high grazing pressures results in less water being retained in the landscape and reduced dry season river flows.

To improve water management, many grasslands are being planted with trees or allowed to progress to shrubland. However this may be an over-reaction that leads to other problems as is evidenced in semi-arid zones such as the Edwards Plateau of the USA (Scholes & Archer, 1997), in Spain (Bellot *et al*., 2001), in India (Sikka *et al*., 2003), and with the invasion of Australian *Acacia* spp. in South Africa (Dye & Jarmain, 2004). In each case water yield in rivers declined. In environments where grasslands have been a significant part of ecosystems, learning to manage them appropriately would be preferable to altering the ecosystem. Recharging aquifers can be better for human health as there is then a reduced risk of pathogens (David & Mazumder, 2003). As a minimum, domestic water supplies need to come from water collected over high grass cover.

Dryland salinity and soil acidification

Australia has the reputation of being the world’s driest inhabited continent, yet salinity caused by excess water in the wrong parts of the landscape is a major problem in both irrigated and dryland agriculture. Up to 17m ha of Australia’s more valuable crop and grassland is at risk of salinisation by 2050 (National Land and Water Resources Audit, 2001). Induced salinity has been known since land clearing, agriculture and irrigation developed, affecting environmental values (Mahmood *et al*., 2001).

Accelerated soil acidification is recognised as a major degradation issue that affects the sustainability of current production systems in both temperate (Ridley *et al*., 2004) and tropical (Noble *et al.,* 1998) environments. Short-term annual pasture legume leys are now recognised as a significant cause of acidity (Ridley *et al.,* 2000; Noble *et al*., 2002). The symptoms are less visible than those that occur with erosion and salinity and the gradual decline in production is often ascribed to other factors such as season. Declining acidity typically results in toxic levels of aluminium developing (Scott *et al*., 2000), and some 24m ha of southern Australia are now affected (Cregan & Scott, 1999). Developing acidity under grasslands has long been recognised in Europe where lime is regularly applied.

How have these problems arisen? In general, salinity and acidity result from a substantial change in land use practice that has altered the hydrological balance from catchment to regional scales. Salinity tends to be worse in regions where annual rainfall is less than evaporation rates, allowing salts to accumulate. Excessive nitrate from legume-dominant swards and livestock urine patches, coupled with excess drainage results in nitrate leaching, all contribute to soil acidification. Management of salinity and acidity requires control over the partitioning of the water balance and the depth of water tables. Pressures to extract increasing returns from livestock caused by declining terms of trade has led to high grazing pressures and significant deterioration in the perennial species base - commonly to less than 20% composition, which exacerbates these problems (Moore, 1970; Kemp & Dowling, 1991; Kemp & Michalk 1993). Similar problems occur throughout the world.

The risks of acidification and of salinity in grasslands can be reduced by the use of perennial plants to use more water and capture nutrients throughout the growing season (Ridley *et al*., 2000; Noble *et al*., 2002). Management practices to increase/maintain the perenniality of grasslands are being developed (Kemp *et al*., 2000; Michalk *et al*., 2003b). Both perennial grasses and strategically placed trees and shrubs (if they cover 16-22% of the catchment) have a role (White *et al*., 2002). The aim is to manage recharge or discharge to levels similar to natural ecosystems (Hatton & Nulsen, 1999). Engineering solutions (Mahmood *et al*., 2001) are too expensive for many types of grassland. A further strategy is to plant species that can be productive and help maintain ecosystems under saline (Cocks, 2001) and acid soils (Scott *et al*., 2000). In central New South Wales, Australia deep drainage was reduced in the order; native C3 grasses < sown C3 grasses < mixed C3/C4 grasses, when present at the same level of herbage mass (Packer *et al*., 2003). The greater the area of perennial herbage plants the less the need for trees (Dunin, 2002). Studies of Mediterranean systems (Joffre & Rambal, 1993) have shown the proportions of perennial grasslands and trees needed to manage the water balance and to capture nitrate. The wider use of lime for acid soil management is restricted to higher rainfall, more fertile and profitable soils.

Economics of water management on grasslands

For most farmers, management of grasslands to alleviate water, salinity and acidity problems is of only secondary concern, compared to obtaining an economic return from livestock production (Pannell, 1999). The proportion of a farm that is sown to perennial plants is then more an economic than an environmental decision. Australian work has found though that the level of use of perennials promoted through traditional education and extension is less than required to halt expansion in saline areas (Bathgate & Pannell, 2002). Achieving a better environmental outcome will depend upon farmers receiving prices for their products that reflect the environmental services delivered e.g. clean water, or from direct subsidies.

Managing nutrient loss in grasslands

Intensive grassland production

Intensive grassland production has come to rely on the identification and alleviation of mineral deficiencies that limit plant growth. Fertiliser application - particularly nitrogen, has significantly increased productivity of intensively managed tropical and temperate grassland systems (ten Berge *et al*., 2002). However, the environmental effects of eutrophication of surface and ground water due to nutrient leakage are now evident at regional and global scales (Oenema *et al*., 2003). Nutrients in animal faeces and urine can be utilised for growing plants or are serious sources of pollution (ten Berge *et al*., 2002). As previously argued, application of the 'law of the minimum' fails within a sustainability context. There is a need to balance these conflicting goals of profitable production and environmental protection in fertiliser management. The key issue would seem to be the better control of nutrient leakage from farms; though within a farm some nutrient movement can be accommodated.

Nitrate leakage is a major issue (McGechan & Topp, 2004, Rimski-Korsakov *et al*., 2004). Leaching losses from grasslands are generally low compared to cropping systems, but can exceed 34 kg N/ha per year - the limit set by the EU Nitrates Directive to maintain the groundwater nitrate concentration below 50 mg/l (Anon., 1991). In Belgium, laws limit residual 'post-harvest' soil nitrate-N to <90 kg N/ha in the soil profile (0-90 cm) between 1 October to 15 November (Nevens & Rehuel, 2003). In the Netherlands, farmers have to maintain records of nutrient use and are taxed on nutrient surpluses generated from their farms, with penalties up to €400/ha for livestock producers (Ondersteijn *et al*., 2002).

Despite this leakage, farmers are reluctant to reduce nitrogen applications because of the decline in livestock performance that results (Valk *et al*., 2000). An analysis of fertiliser strategies in Europe suggested that focussing on efficiency provides the best means to reduce leaching losses and minimise off-site impacts (Ondersteijn *et al*., 2002). Only 30-50% of applied N and ~45% of applied P, is typically taken up by target plants (Smil, 1999; 2000). Improved nutrient-use efficiency can be achieved. Applying fertiliser during periods of peak plant demand, placing fertiliser nearer plant roots and using smaller, more frequent applications all have the potential to reduce nutrient losses while maintaining yield and quality (Tilman *et al*., 2002).

Integrated landscape management can complement paddock measures to effectively control nutrient fluxes and leakage within catchments. As with acidity management, perennial grasses provide a sink to effectively capture or trap nutrients, often as part of water flows (Schilling & Wolter, 2001); capturing nitrate reduces the development of acidity. Buffer strips with 5m of grassland and a line of trees can effectively trap nitrate in soil water flows (Borin & Bigon, 2002). Nutrients can be tied up in less palatable species (Myklestad, 2004); this may be useful in a landscape context, but not for productive grasslands.

Extensively managed grasslands

Extensively managed grasslands depend on nutrients released from parent material and organic matter by biological and chemical processes. These grasslands rarely receive fertiliser; hence legumes often play a key role in productivity. Nutrient release from stored organic pools depends on litter quality, environmental conditions and the level of microbial activity (Swift *et al*., 1979); subsequently these nutrients need to be captured by desirable perennial grasses. Less palatable plant species tend to lock up nutrients and reduce grassland productivity (Moretto & Distal, 2003). Grasses with a high C:N ratio immobilise nutrients due to slow decomposition rates (Hobbie, 1992).

There are large amounts of N and P that are unavailable to plants, and developing management strategies to release more of these 'fixed' nutrient pools is an obvious area for research. Better nutrient management would require sequestration of mineral nutrients within more readily available organic pools, the retention of those pools in the system and then the managed release and capture of nutrients by desirable plant species. In practice this would involve using grazing tactics to maintain litter and retain higher quality plant species to minimise nutrient loss. Overgrazing is arguably the biggest single cause of nutrient loss in extensive grasslands. Wind erosion and nutrient loss in Chinese grasslands can be clearly linked to adverse grazing practices (Dong *et al*., 2000; Michalk *et al.,* 2003a; Li *et al.,* 2004).

Managing carbon and energy

The energy in organic carbon compounds within grasslands is central to their productivity and environmental values. Carbon sequestration is now also a major management objective as elevated atmospheric CO_2 concentrations associated with increasing global temperatures and more variable rainfall patterns are a major concern.

Native grasslands that have never been heavily utilised usually have high organic carbon levels. In extensive grasslands 90% of organic C is below ground (Schuman *et al*., 1999). Elevated atmospheric CO_2 is increasing, in part due to land use changes (Vitousek *et al*., 1997) especially the conversion of large areas of grassland to crop production (Scholes & Noble, 2001). Cultivation of the grassland steppe in China decreased soil organic carbon (SOC) by 25% in 8 years, rendering the soils highly susceptible to erosion (Wu & Tiessen, 2002). The challenge for grasslands is to reverse the losses of CO_2 by storing more in plant and soil organic matter, and to be a net 'sink' for carbon to help minimise adverse environmental impacts (Vleeshouwers & Verhagen, 2002); this also aids water and nutrient management. During the restoration phase of grasslands the rate that carbon is sequestered can be high, relative to grasslands in a 'maintenance' phase (Schlesinger, 1990; Fisher *et al*., 1994). As with earlier discussions, the more perennial plants there are in the system, the more carbon is sequestered. Grazing strategies need to retain litter and utilise forage at intervals that maximise the storage of carbon in the soil. Farming systems where pasture phases are wedged between cropping cycles pose a continuing problem to accumulate C.

Grasslands are not part of the current Kyoto protocol accounting period for 2007-2012, but their vast area makes this resource a potential sink, exceeding that of forests. Payments for carbon sequestration could make the difference between profit and loss for many livestock systems. However, this requires that a commercially realistic system for verification be developed. Grasslands not only capture and store energy, they are often significant consumers of energy and from an environmental perspective these terms need to show a positive balance. It is clear though that the energy balance becomes more negative as livestock production is intensified and manufactured inputs increase, especially N fertiliser (Kelm *et al*., 2004), chemicals and fossil fuels. This can be offset to some extent by the use of legumes and farm manure. Ultimately accounting procedures will need to consider the net energy balance if society is to make effective judgements about the sustainability of grassland practices.

Managing biodiversity

Biodiversity and production

Biodiversity is crucial to the productivity of grasslands, though an understanding of the numbers and types of species that optimise production is still to be determined. Many agronomists assume that grass plus clover equals a good pasture; but is this so? Early work in small plots suggested that maximum productivity occurred when 6-10 plant species were present (Tilman, 1996). At small scales sometimes fewer species were sufficient to maximise grassland production (Nicholas *et al*., 1997). Recent work in small paddocks (<2 ha) where each had > 10 species, suggested that 10-20 species may be optimal for productivity. The net primary productivity of those paddocks declined as species number increased from 20-50 (Kemp *et al*., 2003). Arguably the optimum number of species would be expected to increase as the paddock area and number of different resource niches increase.

Not all species are equal; plant functional type is important. Perennial grasses can dominate grasslands (Tilman, 1996) consuming most of the resources. However, if the fertility is low they may be less competitive and minor species become more frequent (Kemp *et al*., 2003). The importance of plant functional type over species *per se* supports the theory of species redundancy; e.g. *Lolium perenne* can be replaced by *Festuca arundinacea* (tall fescue) in some environments without any significant impact on grassland productivity. An implication for native grasslands is that management to conserve minor species that are part of a common plant functional type, may not be important for the productivity of the grassland.

One or two species are unlikely to dominate natural grasslands. Invariably other species invade supporting the view that stable grasslands require many species. ‘Weeds’ are frequently the biggest issue confronting farmers. Typical mixtures of grass and clover could be augmented with other forbs and ‘gap fillers’ as the later plant types frequently invade swards. The release of cultivars of *Cichorium intybus* (chicory) (Rumball, 1986) and *Plantago lanceolata* (plantain) are a revival of an old practice (Foster, 1988) that fell out of favour during the twentieth century. More diverse grasslands can reduce invasion of other species (van Ruijven *et al*., 2003). Managing grasslands to enable existing species to utilise more resources e.g. by maintaining higher mean levels of herbage mass, can also restrict weed invasion (Badgery, 2003; Meiners *et al*., 2004).

Nature conservation

High grazing pressures can lead to a degradation of grasslands that invariably leads to the loss of species, while conservative practices with low grazing pressures usually retain species. However, an optimal curve related to standing biomass may apply (Grime, 2002). Grassland use ranges from commercial livestock production to wildlife tourism. To attain production and biodiversity goals, the amount of forage utilised needs to satisfy the needs of all relevant herbivores, and enable all the desirable species present (including native species), to persist over the long term.

In grasslands that have been utilised for production, it is reasonable to assume that any rare and endangered species have either been lost long ago, or if still present are being maintained under current management practices. Experience in Australia has been that grassland areas that become part of the National Park system need to be grazed otherwise unwanted species invade and threaten that grassland (Lunt, 2003). For grasslands across southern Australia

(Kemp *et al*., 2003), native plant species in mixed grasslands were maintained if the average herbage mass did not decrease below 2 tDM/ha. This provided farmers with a simple management guideline to conserve those species.

Management for wildlife is becoming an increasingly important economic activity e.g. 'Ducks Unlimited' in North America are funding habitats (there are 50 million bird watchers in the USA and Canada), South Africa now has 45,000 private game reserves. Problems can arise where a single species becomes the sole focus for management, which can have adverse consequences for the rest of the ecosystem. Limited culling of animals and resultant over-grazing so that tourists can more readily see wildlife is an increasing problem.

The biggest threats to species conservation are changing land use. Many grasslands are now dominated by non-preferred species and, or invaders from other environments. To restore rare and endangered species in these circumstances can be an expensive task e.g. transplanting individual grass plants (Hocking, 1998). Little work has been done on the restoration of rare plant species in grasslands. Some disturbance of the ecosystem is required to enable any plant to establish. Knowledge of the size of suitable micro-sites can then help design suitable management practices (Bullock *et al*., 1995). Gap sizes can be varied with grazing tactics. Ecological theory suggests that species richness is maximised at intermediate levels of disturbance (Huston, 1979).

An increasing area of interest is the maintenance of meso- and micro-fauna within grasslands, in part because of their critical roles in cycling nutrients and energy. In a study on a range of grassland systems in central NSW, Australia, the majority of soil insect species were retained across a range of grassland systems, but the proportions changed (Reid, 2004). In Wales retaining a higher average herbage mass in summer resulted in more *Coleoptera* (beetle) species within the grassland, especially those dominated by native plant species (Dennis *et al*., 2004). It was considered that these effects were constrained by the previous history of the grassland, e.g. drainage, fertiliser and lime inputs, and botanical composition. Studies on invertebrate communities in grazing systems indicate however that more intensively managed grazing systems can have lower invertebrate richness and abundance than ungrazed or conservatively grazed grasslands (King & Hutchinson, 1983). High fertiliser inputs can lead to species-poor swards, even years after fertiliser applications cease, which may be the cause of some of the effects noted (Walker *et al*., 2004).

Strategies for managing biodiversity can focus at the level of the paddock, property and landscape. Given the ways farms are managed it may be preferable to focus biodiversity management at a landscape level. This approach is reflected to some extent in EU policies for grassland restoration and management (Smith *et al*., 2003). A mosaic of different fields connected by non-cropped habitat is known to increase diversity of breeding birds, ground beetles, spiders and butterflies (Benton *et al*., 2003). Using a mosaic approach enables species to move between sites to avoid creating islands that then limit the viability of populations (Poschlod *et al*., 1998).

Categorisation of grasslands according to state

Given the world's need for food, fibre and fuel from grasslands, the density of humans and the difficulties of enhancing the environment in all cases, is it possible to categorise the world's grasslands to achieve realistic goals for production and the environment? There are often three broad groupings where different management practices would apply.

- *Healthy*: Those areas where grasslands are predominately in a native state; where there are minimal or readily manageable environmental threats; where current levels of production are appropriate and can be maintained with current knowledge.
- *Disturbed:* Those areas where more intensive practices often apply; where fewer native species exist and more careful management is required to manage nutrient leakage, soil water etc. Knowledge may be insufficient to achieve a good balance between the environment and production.
- *Dying:* Very disturbed areas often subject to intense use, e.g. continual reseeding and cropping, and where there may be an almost complete absence of native species and where there is a high risk of adverse effects on the neighbouring environment. Such areas may not be realistically restored to an environmentally friendly state, and the management objective may be more directed to preventing adverse impacts on neighbours. These areas though may produce much of the food for society, which raises additional issues about society wanting cheap *vs*. clean and green food.

Applying this concept to grassland management may be the way forward. In some ways this is already being done with more 'pristine' areas being incorporated into parks and farmers being subsidised to look after such areas on their farms, while the more intensively used areas are being subject to increased regulation to prevent damage to surrounding environments. If this concept is applied to grassland research, then the area of highest priority may be the 'disturbed' category i.e. those areas where the environmental values can be enhanced and where levels of production can either be sustained or even enhanced, cost-effectively. This category may currently be the less regulated and consequently is where the development of better practices and more self-regulation is possible. Unfortunately many policies focus on the 'healthy' and 'dying' lands where there can often be a sense of emergency.

To continue to provide food for the world's ever-increasing population will require acknowledgement of a cost in terms of some leakage impacts from the more intensively used grasslands. The worst cases are the cities where it would be impossible to remove all adverse environmental impacts; other categories of landscape use may need to be considered in the same light.

Conclusions

With the majority of the world's grasslands considered to be degraded to some degree, how can the need to achieve the levels of food, fibre, fuel and medicine production required be satisfied, while enhancing the environment? Well-managed grasslands based upon improving the perenniality of the ecosystem, should retain species and manage water, nutrient and energy cycles with reasonable efficiencies, and still achieve suitable levels of production. This can be assessed by monitoring species composition, the quality of water coming from the catchment and the efficiency of nutrient use over the medium to long-term. There is a requirement that these needs are translated into tools that farmers can use daily to track their progress and to know if their systems are sustainable. Evidence needs to be provided that recommended tactics and strategies are compatible with normal farm management and economically acceptable.

Many societies now expect that agriculture will look after the environment. The 'polluter pays' principle however, has not always been applied in agriculture, as many of the environmental values often reflect societal wants for enhancement e.g. biodiversity, as opposed to outright pollution. The benefits from remedying environmental problems do not necessarily return to the farmer, they often return to the community at large, even across national boundaries. These effects mean that there is a good case for direct community payments to solve environmental problems. An alternative of extracting market premiums for good environmental practices has had only limited success, and is difficult to apply universally to remedy general problems. Throughout this paper it has been argued that a case exists for direct or market-based payments for environmental/ecological services, and many grasslands could be used for these purposes e.g. storing carbon, delivering clean non-saline water, and maintaining biodiversity. Practical ways of achieving this needs to be developed, as encouraging desired environmental outcomes from grasslands often requires farmers to go beyond normal commercial boundaries, even though there are some synergies that can be explored. Such payments need to be global in approach as many of the environmental problems of grasslands occur in the developing world.

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