Sustaining productive pastures in the tropics
5. Maintaining productive sown grass pastures

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Abstract

Sown grass pastures in the tropics and subtropics are initially productive, but productivity declines with age, a process commonly referred to as run-down. Run-down is often associated with loss of desirable species. Nitrogen (N) deficiency is the major causal factor.

The initially high production of sown pastures is a transient consequence of increased available N and water that accumulates during fallow, and the run-down condition is the normal equilibrium. The severe N deficiency in soils with apparently adequate total N is due to progressive immobilization of N and limited mineralization of humic material.

To increase the productivity of run-down pastures, external N must be supplied or mineralization of N from either soil organic matter or plant residues must be enhanced. Most potential solutions require either external inputs or exploitation of finite soil reserves.

Potential management options under investigation that may increase productivity by increasing N supply include rotations of pastures with annual crops, sowing pasture legumes, fertilizing with N, optimizing grazing management, renovating by cultivation, establishing earthworm populations, establishing beneficial shade trees, and changing to stoloniferous grass types. Another more simple solution is to accept that productivity run-down will inevitably occur and to reduce stocking rate if gain per head is to be maintained.

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Resumen

Las pasturas introducidas en los trópicos y subtrópicos son inicialmente productivas pero dicha productividad decae con la edad, proceso enlazado con el debilitamiento del suelo, el cual es frecuentemente asociado con la perdida de las especies deseables. El principal factor causante es la deficiencia de nitrógeno (N).

La producción inicial elevada de las pasturas introducidas es una consecuencia transitoria del incremento en la disponibilidad de N y agua que se acumulan durante el período de descanso de la tierra, y el consecuente debilitamiento de la misma es un equilibrio normal. La severa deficiencia de N en suelos con un nivel aparentemente adecuado de N total se debe a la inmovilización progresiva del N y a la limitada mineralización del humus.

Para incrementar la productividad de las pasturas de los suelos debilitados, se debe proveer de fuentes externas de N o se debe de intensificar la mineralización del N, ya sea a partir de la materia orgánica del suelo o de los residuos de las plantas. La mayoría de las soluciones potenciales requieren ya sea de insumos externos o de la explotación de las reservas finitas del suelo.

Las opciones de manejo potenciales, actualmente en investigación, que podrían incrementar la productividad mediante la creciente aplicación de N involucran la rotación de las pasturas con cultivos anuales, la siembra de leguminosas, la fertilización con N, la optimización del manejo del pastoreo, la renovación de la tierra mediante el cultivo, establecimiento de poblaciones de gusanos de tierra, establecimiento de árboles de sombra aprovechable, y el cambio a gramíneas de tipo estolonífero. Otra solución simple es aceptar que la reducción en la productividad ocurrirá inevitablemente y disminuir la carga animal si es que la ganancia por cabeza tiene que ser mantenida.

Introduction

Sown grass pastures are initially very productive but productivity generally declines with time. In this paper we examine the pasture run-down phenomenon, consider the reasons behind it, and suggest some management options for reducing the rate of run-down.

The pasture run-down story: inevitable and substantial

Productivity run-down is not new, nor is it unique to northern Australia. The early reports are from Europe. For example, Joulie (1898) wrote: *"Generally speaking, the products obtained from permanent meadows or pastures do not continue uniform, neither are they constant in quantity or quality. The yields, which are at first high, if the grass-land has been laid down under suitable conditions, soon fall off and take a normal level of production, which is maintained for a certain number of years......"* Elliot (1898) described an English example, in which run-down led to lower production and hence lower land rent obtainable by the landlord. In South Africa, Theron and Haylett (1953) reported that unfertilized *Paspalum dilatatum* pasture rapidly deteriorated with age, yielding 200 kg/ha crude protein initially, but only 40 kg/ha 7 years later.

In Queensland, Scattini (1981) cited reports of productivity deterioration of native pastures from as early as 1900. More recently there are reports of decreased grass production (Henzell 1968, Weston *et al.* 1975, Catchpoole 1980) and quality (Robbins *et al.* 1987).

Pasture run-down leads to loss of animal production. In central Queensland, Rudder *et al.* (1982) observed that cattle gained progressively less each year on an improved pasture. With green panic at Brian Pastures, Robbins *et al.* (1987), over several years, observed a linear decline with increasing age of pasture. One-year-old pastures grazed in winter and spring produced weight gains of 74 kg/hd, whereas 5-year-old pasture produced only 35 kg/hd. This occurred despite annual application of N fertilizer. On more fertile brigalow soils, run-down was much slower (Silvey and Jones 1990, R.M. Jones (personal communication)).

Pasture run-down is thus inevitable and substantial in sown grass pastures, and justifies the amount of current research interest.

Causes of sown pasture run-down

Species composition

The loss of productivity of ageing sown grass pastures is not primarily due to replacement of sown grass by native or weedy species. Rather, change in botanical composition of the pasture is a consequence of run-down. Weeds and native grasses usually come in because they are better able to persist and produce under a low N regime. They make better use of available water (G.B. Robbins, unpublished data).

The productivity of a range of grasses is being compared at Brian Pastures (Robbins and Bushell 1986; G.B. Robbins, unpublished data). Pasture age has been more important than grass species in determining cattle growth. For example, weight gains for 6 months from June 1989 were 78 kg/hd on 2-year-old pasture, 37 kg/hd on 5-year-old pasture, and 20 kg/hd on 8-year-old pasture. Although there has been variation, sometimes large, between grass species, no grass has been consistently better than others. Simply replacing one run-down grass species with another species will not in itself provide an increase in productivity. Ploughing out and resowing brings only a short-term boost to production through a temporary increase in available N.

Changes in soil nitrogen availability

Run-down in ageing sown grass pastures can be directly attributed to changes in N availability. There is no measurable net loss of soil total N associated with this run-down (Graham *et al.* 1981, G.B. Robbins, unpublished data, V.R. Catchpoole, unpublished data); rather it is a reduction in the rate at which N is released from organic forms in the soil combined with loss of labile N under grazing. At Narayen there is a sharp contrast between the rapid development of run-down within two years of establishment of a green panic pasture (Myers *et al.* 1987) and the lack of N response of continuous wheat and sorghum even after 20 years (J.S. Russell, unpublished data).

We believe that the initial high level of production in newly established pasture is largely due to a transient boost ("run-up") in available N and water in the soil during the fallow prior to seeding (Robbins *et al.* 1986, Myers *et al.* 1987). The run-down condition is therefore the normal equilibrium. In the run-down state, net mineralization of soil N under green panic was only half that under grain sorghum (Robertson 1988) and two-thirds that under the natural brigalow woodland (Bligh 1990).

The reasons for the relatively slow N mineralization in soil under tropical grassland are complex.

Firstly, the proportion of organic N in the passive pool of soil N (Parton *et al.* 1983) is high, particularly when clay content is high. Therefore mineralization of N from humic material is slow in the absence of cultivation. Much of the N in the pasture must be derived from recycling, either within the plant or through litter turnover.

Secondly, the tropical C4 grass pasture is characterized by the return of large amounts of low quality litter (Table 1). Much of this is derived from the very large below-ground production of roots and crowns (Table 1). N mineralization from this material is very slow because of its high C:N ratio (Robbins *et al.* 1989). Therefore decomposition of litter requires an external source of N and so N is immobilized. Also a high lignin:N ratio promotes the incorporation of N into stable humic complexes.

Table 1. Distribution of nitrogen in different compartments of a green panic pasture at Narayen Research Station (I. Vallis, V.R. Catchpoole and W.B. McGill, unpublished data)

Compartment	Nitrogen	
	(kg/ha)	
Live tops	23	
Dead tops	14	
Crowns	29	
Total tops		66
Coarse litter	27	
Fine litter	82	
Total litter		109
Roots (0-480 mm)		265
Microbial N (0-150 mm)		269
Mineral N (0-150 mm)		13

Other factors causing run-down

Grazing. Grazing generally has only a small influence in exacerbating pasture run-down. Grazing induces a small loss of N if recycling of N within the plant is disrupted. Such recycling of N can be substantial, with movement of N to below-ground parts at the end of the growing season, then back to tops in the next growing season (Clark 1977). If this cycle is broken by net removal from the system via grazing, then in the absence of an input of new N, less production may result.

Nevertheless, the amount of N removed by grazing is small. For example, for a pasture producing annually 5 t/ha in tops, containing 50 kg/ha of N, consider two situations: light grazing whereby 40% is consumed by cattle, and heavy grazing whereby 80% is consumed. Then assume 15% to be retained in tissues, and the remainder excreted, half in urine and half in faeces (Henzell and Ross 1973). If 50% of urine N and 20% of faecal N is lost by volatilization (Vallis and Gardener 1984), then the loss from the system would be 11.9 kg/ha of N with heavy grazing and 5.6 kg/ha of N with light grazing. Losses of this magnitude are small in the context of the total soil N, but may be important in relation to the amounts of N cycling since additional soil N must be mineralized in the next season in order to maintain productivity.

Also, under light grazing most of the N cycling occurs in turnover of low quality litter whereas with heavy grazing most of the N cycling occurs through dung and urine. Since some N is lost via volatilization of N in dung and urine, there will be a net loss of N from the system, and an eventual drop in productivity, when too much of the labile N in the system enters this pool. At modest intensity of grazing, this loss is smaller, and the increased availability of the N that is not lost stimulates productivity (McNaughton 1985).

Drought. Little is known regarding drought and run-down. However, drought exacerbates the effects of overgrazing in promoting changes in species composition. It is likely that N deficiency is less severe in perennial pasture under drought.

Nature of the grass. The C4 grasses have higher C:N ratios than the C3 grasses. During decomposition of C4 material there is a greater need for an external N source; in other words, N is immobilized. This reduces the amount of available N in the soil to support grass regrowth. There is evidence from southern Africa (Barnes 1960) that a stoloniferous grass was less susceptible to run-down than a bunch grass. If this is so then it may be that stoloniferous grass puts less resources into below ground material, and therefore there is less N turnover in this material. This could reduce the amount of N immobilized. This possibility has not been tested.

Hypothesis for fertility maintenance

What does this understanding of the process of run-down allow us to say about how we may avoid or slow run-down?

Provided that desirable species are retained, productivity of a run-down pasture is sustainable, albeit at a relatively low level. It is a system in dynamic equilibrium, where the animal removal and gaseous loss of N is probably in balance with the inputs from N fixation and deposition. So it is natural that production should tend towards this equilibrium after the early 'run-up' condition following establishment of a sown pasture.

The only way to avoid or slow run-down is to provide additional N to the grass, either by providing for additional inputs or by increasing the exploitation of existing N reserves. Additional inputs of N need to come from supply as fertilizer or through increased N fixation. Such inputs have a cost.

Increasing production through increased use of existing soil N implies 'mining' of soil N. If animal production is also increased, so too will gaseous loss of N and animal removal increase. Unless inputs from nonsymbiotic N fixation, usually only a few kg/ha from grasses (Weier 1980), are increased, there would be a small net loss of N from the system and soil organic matter will decline, though very slowly. Technically such a system is not sustainable in the long term.

Management options for overcoming run-down

Crop-pasture rotations

The concept is simple: both crop and pasture benefit in the long term, since the crop takes advantage of organic matter accumulated under a pasture, and the pasture takes advantage of N released during cultivation.

However, this is still a 'mining' situation unless the pasture includes a productive legume, such as lucerne or medics (Clarkson *et al.* 1991; Lloyd *et al.* 1991). Current work in southern Queensland is testing the effectiveness of ley pastures for increasing the productivity of once-fertile land (Dalal *et al.* 1991).

The success of crop-pasture rotations in southern Australia during much of the 20th century has been attributed to the relative economics of the pasture and crop components during this time (McCown *et al.* 1988). Likewise their unpopularity at other times, including the present, reflects the higher profitability of either one or the other component. Nevertheless such rotations offer sustainable, low-input systems. A challenge exists to make these systems work in Australian tropics and subtropics. However, they are only appropriate on soils, such as the brigalow and downs soils, that are suitable for cropping.

Pasture legumes

Persistent and productive legumes growing with grasses in a permanent pasture may be a better option. However, the benefit that N-fixing legumes pass on to associated grasses is usually less than commonly believed. Seldom can they completely prevent productivity decline. Most sown grass pastures require at least 100 kg/ha of fertilizer N to maintain productivity. Robbins (1984) has argued that a legume would need to fix about 125 kg/ha of N to be applied annually to maintain a legume-grass pasture at such a level.

The amount of N fixed depends on the growth of the legume (Vallis and Gardener 1985). Stylos, for example, obtain about 80% of their N from fixation, but this may vary between seasons and sites from virtually nil to more than 100 kg/ha of N per season. Dryland medics at Roma have produced 3000 kg/ha DM (Clarkson et al. 1991) which, assuming fixed N is 2.5% of dry matter, would indicate about 75 kg/ha of N fixation.

However, there are no commercially available tropical herbaceous legumes with proven adaptation to clay soils. The best adapted legume to clay soils is leucaena (*Leucaena leucocephela*), but only a small proportion of sown pastures on clay soils contain legumes.

N Fertilizer

N fertilized pasture is dealt with elsewhere in this issue (Teitzel *et al.* 1991). Here we restrict ourselves to some comments relevant to maintaining productivity of new pastures, or increasing productivity of aged pastures.

Annual applications of N can more than double the production of old sown grass pasture (Pressland and Graham 1989, Peake *et al.* 1990). However 200-250 kg/ha of N per year is required at Brian Pastures to make a 5-year-old pasture as productive as a 1-year-old pasture (Robbins 1984). This amount of fertilizer, costing say $180/ha, would only give a return in the year of application of $110 at today's beef prices. However, R.M. Jones (unpublished data), at Narayen, found that productivity was maintained by 100 kg/ha of N applied each year, and that the additional production was similar in value to the cost of fertilizer and its application.

Robbins (1984) measured pasture run-down with an annual application of 60 kg/ha of N. Total shoot and root uptake in 1-year-old pasture was 53 kg/ha of N compared with 40 kg/ha of N in 2-year-old pasture. In order to achieve an extra 13 kg/ha of N plant uptake, and assuming plant uptake of 20% of the extra N applied, a total annual application of 100 kg/ha of N would be needed. This option is currently being tested at Brian Pastures.

Grazing management

Studies in the Serengeti grasslands, a productive and stable natural ecosystem (McNaughton 1979), have indicated that productivity was enhanced by moderate grazing pressure but depressed by high grazing pressure. Room for animal migration was considered to be an important component of the optimization. Where pasture productivity is declining with age, this should be matched by reduced stocking rate if gain per head is to be maintained. Similar concepts exist for cattle grazing systems. The major problem here is that of coping with variable rainfall, or of responding to changing weather patterns. Reliable long-term weather prediction could help the manager optimize his grazing pressure. There is scope for further studies on grazing pressure as a management tool to reduce the impact of run-down.

Pasture renovation

Run-down pastures have been renovated by cultivation — either light cultivation without killing the pasture (renovation), or ploughing out and re-seeding (re-establishment). Cultivation does two things — it stimulates mineralization of soil organic matter by disrupting aggregates and by conserving soil water, and it also stimulates the turnover of N in plant residues by mixing surface litter into the soil and killing a portion of the grass root system.

Renovation produces variable results for pasture production. Catchpoole (1984) obtained increased green panic production in each of three years with a mean yield of 8.0 and 9.5 t/ha with the undisturbed and renovated systems. However, Graham *et al.* (1986) obtained no response, and Grof *et al.* (1969) found that renovation decreased production. We are aware of other unpublished data showing benefits to renovation in some cases and no effect in others. In recent work, there was no response to renovation by cultivation unless green panic seed was applied at the same time (V.R. Catchpoole and K.F. Gould, unpublished data). Clearly renovation will not work if the right species are not present. On a duplex soil in the brigalow region, only ploughing-out and re-seeding gave a positive response (Graham *et al.* 1986).

Renovation also produces variable results in cattle production. In current work, renovation has generally increased pasture growth and quality, controlled woody weeds and allowed the establishment of Seca stylo at four sites (G.B. Robbins, unpublished data). However, at only one site has better cattle production resulted. Looking at the variation in response to renovation between Narayen (consistent benefits), Brian Pastures (variable response), the duplex soil (no benefit) and the regional sites testing animal production (variable responses), we conclude that the benefits are dependent on the relative fertility of the soil, how run-down the pasture is, the intensity of renovation, and seasonal conditions after renovation. Although renovation is used by some producers, it is unlikely to be recommended widely unless the response can be made more reliable.

A response that is probably of the same nature as the renovation response is that obtained by chemical thinning. In Wyoming blue grama grassland production was increased by spraying alternate strips with herbicide (McGinnies 1984). We know of no similar experience with tropical grassland.

Presence of Earthworms

The idea of a biological renovation has led to an interest in introduction of earthworms into pasture soils. Introduced earthworms have been highly successful in New Zealand (Stockdill 1966), but interest in Australia has only recently been rekindled (Davidson 1988/89). Catchpoole (unpublished data) has demonstrated, in intact cores, that introduction of an earthworm, *Pontoscolex corethruris*, increased the growth of green panic. Research is now needed to find species adapted to the soil and climatic conditions of our grasslands.

Partial Shading

Ageing pastures of a range of grasses have shown a positive response to partial shading (Wilson and Wild 1991, Wilson *et al.* 1986) (Table 2). The mechanism for this response is not yet clear, although there are suggestions that retention of water at and below the soil surface may be an important factor. We know of no examples where self-shading by old standing dead grass has produced such a response; rather removal of this material is known to stimulate growth. However, shading by trees or shrubs may stimulate grass growth. Thus *Paspalum notatum* under *Eucalyptus grandis* trees has been shown to be more productive than grass without shade (Wilson and Wild 1991), and *Panicum maximum* yielded more under a canopy of *Albizia lebbeck* than it did in the open (Lowry and Jones 1988).

Table 2. Effect of shade on yield of tops and leaf nitrogen concentration of tropical grasses — (Wilson and Wild 1991).

Pasture Type	Yield of tops[1]			Leaf nitrogen[2]	
	Shade	Sun	Relative effect	Shade	Sun
	(t/ha)			(%)	
Clay soil					
Green Panic					
Irrigated	23.4	16.3	+44%	2.81	2.21
Not irrigated	15.6	12.4	+26%	2.89	2.23
Buffel	15.8	16.6	−5%	2.08	1.64
Rhodes	15.1	11.4	+32%	1.53	1.34
Sandy soil					
Green Panic					
Irrigated	13.4	9.1	+48%	2.64	2.39
Not irrigated	9.7	6.6	+48%	2.64	2.58
Buffel	13.6	10.8	+26%	1.79	1.49
Spear grass	7.5	6.6	+14%	1.38	1.49

[1]Cumulative yield total over 5 harvests
[2]In youngest fully expanded leaf in May 1989

Successful exploitation of shading would presumably depend on minimizing competition for water between the shrub or tree and the grass. A lack of information on the nature of root systems of possible shrub and tree species hampers this research.

The nature of the grass

Our experience of run-down is mostly from perennial bunch grasses. Because of the suggestion that stoloniferous grasses are less prone to run-down (Barnes 1960) there may be a need for testing this idea under our conditions.

Conclusion

The problem of run-down is widespread and costly. There is a range of potential management options for coping with pasture run-down, but these remedies have their cost. Not all are sustainable in the long term, most require inputs of one kind or another, and such inputs may be costly in time or money terms and therefore require careful evaluation.

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