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Use of Perennial Grass in Grazing Systems of Southern Australia to Adapt to a Changing Climate

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1. Introduction

Grasslands and rangelands occupy over 70% of the earth's land area (Holechek et al., 2004; World Resource Institute, 2000), and are a major source of meat, milk and fibre production in the world. The rising demand for meat and milk in the past 30 - 40 years and the adverse impact from climate variability have placed great pressure on the productive and sustainable use of grazing lands (Delgado, 2005; Nie & Norton, 2009). By 2020, it is predicted that developing countries will consume 72 m tons more meat and 152 m tons more milk compared to 2002/03 whereas developed countries' increases will be 9 and 18 m tons for meat and milk, respectively (Delgado, 2005).

Australia is the world's driest inhabited continent. Half of its total land area has an average annual rainfall (AAR) of less than 300 mm. Around 60% is used for agriculture, of which over 90% is used for grazing (Peeters, 2008). A particular feature of the continent is the high rainfall variability which makes selecting the right pasture species/cultivars, optimising pasture and grazing management and avoiding overgrazing very challenging. About 5% of Australia's grazing lands have been sown to introduced plant species and these improved pastures support a large proportion of the domestic livestock. The improved pasture species are productive and generally have high nutritive characteristics; however, their persistence is often poor due to the limited capacity to sustain a suite of varying soil, climatic and management conditions. A pasture survey in south west Victoria revealed that the majority of pastures were dominated by low-producing, 'unimproved' grass species (Quigley et al., 1992), and similar results were found in southern New South Wales (NSW; Virgona & Hildebrand, 2007).

The main perennial pasture grasses sown in southern Australia are perennial ryegrass (*Lolium perenne*), phalaris (*Phalaris aquatica*), tall fescue (*Festuca arundinaceum* syn. *Lolium arundinaceum*), and cocksfoot (*Dactylis glomerata*) (Reed, 1996). These grasses differ in their requirements of rainfall, temperature and soil type and fertility for growth, therefore have a varying degree of adaptation in different regions. Plant breeders have developed new cultivars to improve one or more attributes for each of the grasses. Agronomists working with other specialists such as animal and soil scientists have developed management systems to accommodate the expression of the attributes from the new cultivars. At present there are large variations between cultivars within each species, not to mention between species.

In rangelands and marginal land classes such as steep hill or stony country where improved perennial grasses cannot be sown or do not persist, Australian native grasses are often the dominant perennial species. Native grasses have grown and evolved in Australia for millions of years, and are generally well adapted to the soil and climatic conditions. While there has been debate on the yield and nutritive value of native grasses compared with improved exotic species, there is a general consensus that native grasses are better adapted to low fertility soils and low input farming systems that receive low and unreliable rainfall.

Climate change projections for Australia indicate increasing temperatures, varying rainfall patterns across regions, and elevated atmospheric carbon dioxide (CO₂) concentrations (CSIRO & BoM, 2007), which are likely to affect the productivity of pasture-based systems, although the overall effect is likely to vary regionally, depending on the combination of those changes (Harle et al., 2007; Howden et al., 2008; McKeon et al., 2009). The predicted long-term (up to 2070) rainfall patterns indicate a higher chance of rainfall reduction in southern than in north, central and eastern Australia (CSIRO & BoM, 2007). The rainfall reductions in southern Australia are projected to be largest in winter and spring.

Research into the responses of perennial grasses to climate, soil and management factors has long been a major target for agronomists, breeders and physiologists to improve the resistance/adaptation attributes and management of these plants. The challenge is how we can place these responses and improved attributes in a systems context and achieve production and sustainability goals in practice. This chapter discusses the past and current research on perennial grasses and their management systems that may lead to the development of adaptation strategies to climate change in southern Australia.

2. The role and performance of perennial grasses for Australian grazing industries

Historically, Australia's flora did not evolve under grazing by large groups of herbivores (Moore, 1970). Native species (predominantly native perennial grasses) were adapted to low fertility soils, periodic burning and infrequent grazing by soft-footed animals at low grazing pressures. The process of deterioration of native pastures started from the early 1800s when cloven-hoofed animals in closely managed groups were introduced. The failure of early European settlers to appreciate the consequences of the regular pattern of droughts, and the exploding rabbit population exacerbated the process. In the 1890s, severe droughts, livestock death and the demise of the pastoral resources attracted the attention of the press, governments, pastoralists and scientists, which were recognised as a major national problem. In the 1950s, widespread management change and introduction of new pasture species were made to halt pasture decline in many parts of temperate Australia. These included the introduction of temperate perennial grasses and subterranean clover (*Trifolium subterraneum*), the widespread use of phosphorus fertiliser, the formulation of policies to restrict stock numbers, and the development of economic means of rabbit control (Kemp & Michalk, 1993).

Australian native grass is a general term to describe a diverse range of grasses that have evolved in Australia for millions of years. There are about 1000 native grass species in Australia, which are well adapted to the harsh and varying climate, and play an important part in maintaining ecosystem health (Nie & Mitchell, 2006). The agronomic and environmental values of Australian native grasses were generally undervalued until recently when severe environmental problems such as dryland salinity were clearly

demonstrated as being associated with the clearance of native vegetation. Studies (Dorrrough et al., 2004; Eddy, 2002; Nie et al., 2005; Nie & Zollinger 2008; Waters et al., 2000) have found that native grasses not only have significant environmental value, but their agronomic characteristics such as dry matter (DM) accumulation, persistence and nutritive characteristics should also be given more objective judgement as many native species may better adapt to some environments and produce higher amounts and more nutritious feed for grazing animals than improved exotic species.

The introduction of exotic plants and animals with extensive clearing, heavy stocking and ploughing of fields led to the disappearance of most native grasslands, particularly in temperate Australia. However, this did not result in a massive increase in the coverage of grasslands by the improved species. Up to date, the proportion of Australia's grazing lands that have been sown to introduced plant species is still low (approximately 5%; Peeters, 2008), although these improved pastures support >40% of our domestic livestock (Hutchinson, 1992). Improved pastures were mainly sown in medium to high rainfall (>550 mm AAR) environments with high fertiliser and management inputs due to their lack of persistence in harsher environments.

Among the four major improved temperate perennial grasses in Australia, perennial ryegrass is most widely sown in high rainfall (>650 mm AAR) and high fertility zones (Reed, 1996). Most Australian dairy farmers operate in more heavily (compared with sheep and beef) fertilised, high rainfall or irrigated areas and rely almost exclusively on perennial ryegrass. The minimum rainfall required by the grass increases with lower latitudes (e.g. 650 mm AAR for Victoria, 700 mm for southern New South Wales, and 800 mm for northern New South Wales) and decreases with higher altitudes. Perennial ryegrass is highly nutritious, fast establishing and very productive over the growing seasons. It is well adapted to medium to heavy textured soils and generally will not persist on light soils. Drought tolerance and persistence are a limitation of the grass in comparison with other major perennial grasses (Nie et al., 2004; Slack et al., 2000).

Tall fescue and phalaris are commonly used where soils are heavy textured and waterlogging can be severe. Both species are deep rooted and generally tolerate soil moisture stress better than perennial ryegrass (Moore et al., 2006; Nie et al., 2008). They can grow and persist well in medium to high rainfall (>550 mm AAR) environments. Tall fescue has two types with distinct growth patterns, summer active and winter active, which can be used to balance the feed supply across seasons. Both types provide nutritious feed in late spring and early summer although their growth rates vary considerably between summer and winter (Moore et al., 2006). Phalaris is often sown to improve the balance of seasonal feed supply and increase stocking rate in wool and lamb production systems (Reed, 2006). It is sensitive to aluminium toxicity induced by soil acidity (pH in $\text{CaCl}_2 < 4.2$) and the use of lime is needed to aid persistence on acid soils (Reed, 2006).

Cocksfoot is well suited to free drained, light textured soils. It is useful in areas of lower rainfall, strong soil acidity and low fertility. There are three types of cocksfoot: temperate (or continental; ssp. *glomerata*), Mediterranean (or Hispanic; ssp. *hispanica*) and intermediate types (ssp. *glomerata* x *hispanica*) (Voltaire and Lelièvre, 1997). Temperate and intermediate types of cocksfoot are summer active whereas Hispanic type (Spanish cocksfoot) is highly summer dormant. The Hispanic cocksfoot is one of the most drought tolerant among the perennial grass species and can grow and persist well in the Mediterranean regions which receive around 300 mm AAR (Harris et al., 2008).

Other perennial grasses such as tall wheat grass (*Thinopyrum ponticum*), perennial veldt grass (*Ehrharta calycina*), panic grasses (e.g. *Panicum maximum*) and kikuyu grass (*Pennisetum clandestinum*) are also sown in targeted regions or areas of southern Australia. For instance, tall wheat grass is tolerant of high levels of salinity and is used in saline soils where other improved perennial species will not grow (Reed, 2006). Kikuyu grass and panic grasses have been evaluated and sown on coarse-textured soils including deep sands in Western Australia (More et al., 2006).

3. Climate change and perennial pastures

Australia is the hottest and driest inhabited continent in terms of duration and intensity of heat. Temperatures above 45°C have been recorded at nearly all stations more than 150 km from the coast and at many places on the north-west and southern coasts (NATMAP, 1986). Half of Australia's total land area has an average annual rainfall of less than 300 mm and about 80% has less than 600 mm (Fig. 1). In southern Australia, whether in the Mediterranean or temperate environments, rainfall is often winter dominant and highly variable, with frequent droughts lasting up to several seasons.

The main climate change variables that are likely to be important in their impact on perennial grass growth and survival are temperature, rainfall and the concentration of CO₂ in the atmosphere (Cullen et al., 2009; Howden et al., 2008). Since 1910 the average maximum and minimum temperature in Australia have risen by 0.7°C and 1.1°C, respectively (Alexander et al., 2007) and this trend is predicted to continue at higher rates in the next 50 – 70 years (Hennessy et al., 2007). The average annual temperature is projected to rise between 0.4 and 2°C over most of Australia by 2030, with an accompanying increase in the likelihood of extreme hot and wet days (Harle et al., 2007). Potential evaporation (or evaporative demand) is also likely to increase with increasing temperatures.

Annual rainfall in southern Australia has dropped since 1950 (Smith 2004). Predicted further reductions in rainfall together with the increases in evaporation are anticipated to result in up to 20% more droughts by 2030 (Mpelasoka et al., 2007). Projected changes in seasonal rainfall by 2030 range from -20% to +5% for spring rainfall in the southwest high rainfall zone to -5% to +15% for autumn rainfall in the south-eastern wheat-sheep zone (Harle et al., 2007). The most pronounced decreases are predicted for winter and spring, although some coastal areas of the high rainfall zone may become wetter in summer, and some areas of the eastern sheep-wheat zone may become wetter in autumn.

The International Panel on Climate Change projections for the atmospheric CO₂ concentration in the year 2030 range from 400 to 480 ppm, compared to about 280 ppm in the pre-industrial era and 380 ppm currently (Cullen et al., 2009; Harle et al., 2007). The breadth of this range is due to uncertainties associated with different socio-economic assumptions in greenhouse gas emission scenarios, the carbon removal processes (carbon sinks) and the magnitude of climate feedback on the terrestrial biosphere.

The climate change that has been observed in Australia and the likely trend of further changes have shown significant impacts on the grazing industries and the need to develop pasture plants and grazing systems to address the issues (Cullen et al., 2009). While the changes in temperature and rainfall generally have a negative impact on perennial grass growth and survival, the elevated atmospheric CO₂ concentration could promote pasture growth in the absence of other climate changes (Ward et al., 1999). Cullen et al. (2009) predicted a 22 – 37% increase in dry matter (DM) production of temperate grass dominated

pastures in southern Australia, simulated by raising the atmospheric CO₂ from 380 to 550 ppm. These increases will be affected by pasture species (e.g. C₃ vs C₄ grasses) and soil nutrients (Long et al., 2004; Lüsher et al., 2006).

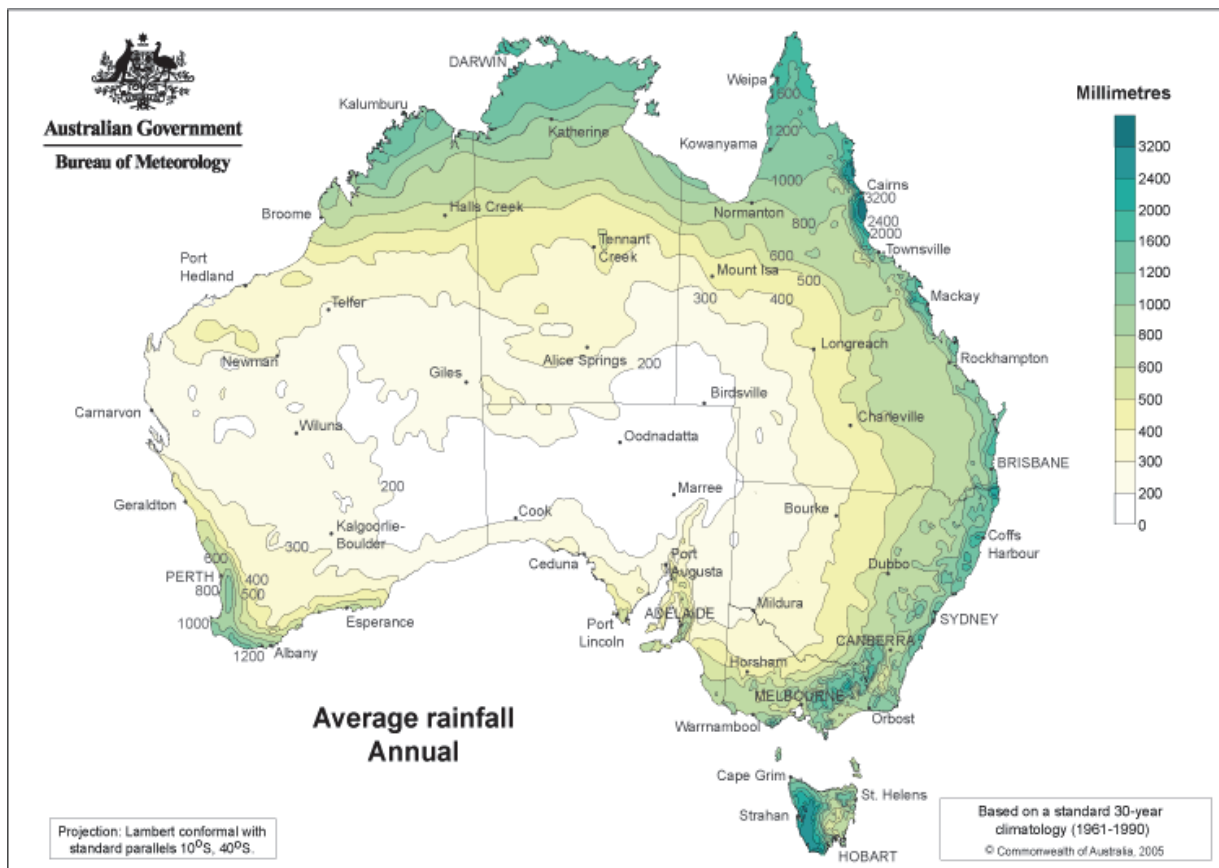


Fig. 1. Rainfall distribution in Australia (Australian Government Bureau of Meteorology Climate Data Online; copyright Commonwealth of Australia reproduced by permission; adapted from Nie & Norton, 2009).

The biggest concerns associated with climate change for Australian grazing industries are the negative impacts of changes in rainfall and temperature which have already been a long-term challenge to ensure sustainability in pasture and animal production. The more extreme temperatures and the reduced and more variable rainfall predicted in southern Australia are likely to shorten the growing season, reduce pasture yield and nutritive value (Harle et al., 2007), and more importantly impose a higher risk for the perennial species to survive and persist (Nie & Norton, 2009). It is therefore imperative to understand the potential role that perennial plants, particularly perennial grasses, can play in a changing climate and develop adaptive strategies and systems that can deliver sustainability as well as profitability for the livestock industries.

4. The adaptive traits of perennial grasses to moisture and heat stress

Rainfall reduction and more extreme temperatures are the two most significant features of the current climate change and projections for future change that could adversely affect temperate perennial grasses in southern Australia. Decline of sown grass species has already

been common in most pastures, because of their poor adaptation to the more severe and more variable climatic conditions (Beattie, 1994). A pasture survey in south west Victoria revealed the majority of pastures were dominated by low-producing, 'unimproved' grass species (Quigley et al., 1992). Similar results were also found in southern New South Wales (Virgona & Hildebrand, 2007). In native pastures, perennial species are predominantly native grasses which are often low in botanical composition due to climate, soil nutrient and management constraints (Garden et al., 2001; Nie et al., 2005).

In response to soil moisture and heat stress, perennial grasses have developed adaptive traits in order to survive under stressful environment conditions. Major traits that have shown to increase the resistance of perennial grass plants to drought and hot weather include rooting depth and summer dormancy. Other traits such as water-soluble carbohydrate (WSC) concentrations in tiller bases may also be beneficial in improving drought tolerance (Volaire & Lelièvre, 1997). Research into these traits or other mechanisms to support plant resistance has been limited to a small number of the species/cultivars. Further research is needed to have a better understanding of these traits for a wider range of grasses and to find or develop more adaptive traits.

4.1 Rooting depth

Rooting depth is a trait that contributes to a species overall strategy of response to water stress. It determines the accessibility of a plant to moisture in the soil profile, which is particularly important for perennial species in avoiding dehydration and coping with environmental stress (water and nutrient deficiency) across seasons, years and landscapes (Levitt, 1980; Nie et al., 2008; White et al., 2003). Therefore, the benefits of deep roots in perennial grasses are expressed and become more critical when plants encounter severe moisture stress.

Rooting depth of perennial grasses are generally much greater than annual grasses (Lolicato, 2000), and can vary dramatically between species, and between the environments in which they are grown. In a study to investigate the performance of a range of perennial grasses in southern Australia (Nie et al., 2008), rooting depth of 11 temperate perennial grasses and one cultivar of kikuyu grass (*Pennisetum clandestinum* cv. Whittet) was measured at two sites (Hamilton and Warrak in western Victoria, Australia) contrasting in rainfall, soil type and slope (Table 1; Reed et al., 2008). The cultivar with the deepest root system (up to 2 m) was Whittet kikuyu grass, followed by phalaris and tall fescue cultivars (rooting depths between 1.12 and 1.5 m at Hamilton and 0.84 and 0.96 m at Warrak). Interestingly, cocksfoot was the lowest in rooting depth at Hamilton, but higher than perennial ryegrass at Warrak, a site with shallower soil and lower rainfall than Hamilton. Mean rooting depth across all species was 1.3 m at Hamilton (ranging from 0.9 to 2.01 m) and 0.9 m at Warrak (ranging from 0.75 to 1.27 m) (Table 1). The differences were associated with differences in rainfall, soil structure and fertility between the two sites (Nie et al., 2008). Hamilton had the higher rainfall over the experimental period and higher soil fertility, which allowed plants to develop roots under less moisture stress and lower nutrient deficiency. The compacted stony-gravel conglomerate layer in the subsoil at Warrak may have also contributed to a more shallow root system.

Field studies to quantify the relationship between rooting depth and persistence in perennial grasses are always challenging, not only because persistence can be affected by many factors (Nie et al., 2004), but also the survival mechanisms of different species vary between species and between cultivars within a species. Nevertheless, regression analysis

Species	Cultivar	Hamilton	Warrak	Mean
<i>Phalaris aquatica</i>	Australian	1.50	0.88	1.19
<i>P. aquatica</i>	Atlas PG	1.49	0.84	1.16
<i>P. aquatica</i>	Holdfast	1.12	0.94	1.03
<i>P. aquatica</i>	Landmaster	1.47	1.11	1.29
<i>Dactylis glomerata</i>	Currie	0.93	0.81	0.87
<i>D. glomerata</i>	Porto	0.90	0.92	0.91
<i>Festuca arundinaceum</i>	Fraydo	1.28	0.89	1.09
<i>F. arundinaceum</i>	Resolute MaxP	1.43	0.91	1.17
<i>F. arundinaceum</i>	AU Triumph	1.39	0.96	1.18
<i>Lolium perenne</i>	AVH 4	1.05	0.76	0.90
<i>L. perenne</i>	Avalon	1.24	0.75	0.99
<i>Pennisetum clandestinum</i>	Whittet	2.01	1.27	1.64

Table 1. Means of rooting depth (m) for various pasture cultivars at Hamilton and Warrak in March 2005 (Nie et al., 2008).

on the data collected over 4 years from the above experiment has shown a positive relationship between rooting depth of the perennial grasses and their persistence (expressed as %change of plant frequency from year 2 to year 4) for most perennial grasses tested except two cultivars, Atlas PG phalaris and Currie cocksfoot at the Warrak site (Fig. 2). However, there was no clear relationship between the two attributes for the same species and cultivar at the Hamilton site, presumably due to the large differences in rainfall, soil and topography between the two sites. The Hamilton site was flat with Brown Chromosol soil and mean annual rainfall of 640 mm (ranging from 523 to 750 mm) whereas the Warrak site was on a slope with Red Kurosol soil and mean annual rainfall of 480 mm (ranging from 438 to 525 mm) over the 4-year (2002 - 2005) experimental period (Reed et al., 2008). The harsher environmental conditions at Warrak allowed the expression of the deep rooting merits of the perennial grasses. Atlas PG phalaris and Currie cocksfoot did not fit well with the regression analysis of the Warrak data, probably because they have different survival mechanisms under water stress. For instance, Volaire and Lelievre (2001) observed that Currie cocksfoot had the ability to continue extraction of soil water at low levels of available soil moisture, suggesting this as a significant factor in its survival under prolonged drought. Apparently increased rooting depth can also improve pasture growth rate and production due to higher accessibility to soil moisture/nutrients and dehydration avoidance under water deficit. Cullen et al. (2009) compared the pasture growth rate and yield between two rooting depths (0.4 vs 0.6 m) by modelling a high greenhouse gas emission scenario in 2070 in a high rainfall perennial grass-based pasture environment of southern Australia. The 2070 climate change projections for the site are 3.3°C increase in temperature and 22% reduction in rainfall in comparison to a 30-year (1971-2000) historical baseline climate. Mean predicted total annual pasture production increased from 10.5 t DM/ha at a rooting depth of 0.4 m to 11.6 t DM/ha at a rooting depth of 0.6 m, largely due to extended growing season and increased growth rate (an increase of 10 kg DM/ha.day) in spring (Fig. 3). The pasture yields were lower than the baseline simulation at a rooting depth of 0.4 m (12.9 t DM/ha). With the deeper root system, the predicted mean annual drainage was reduced from 270 to 252 mm.

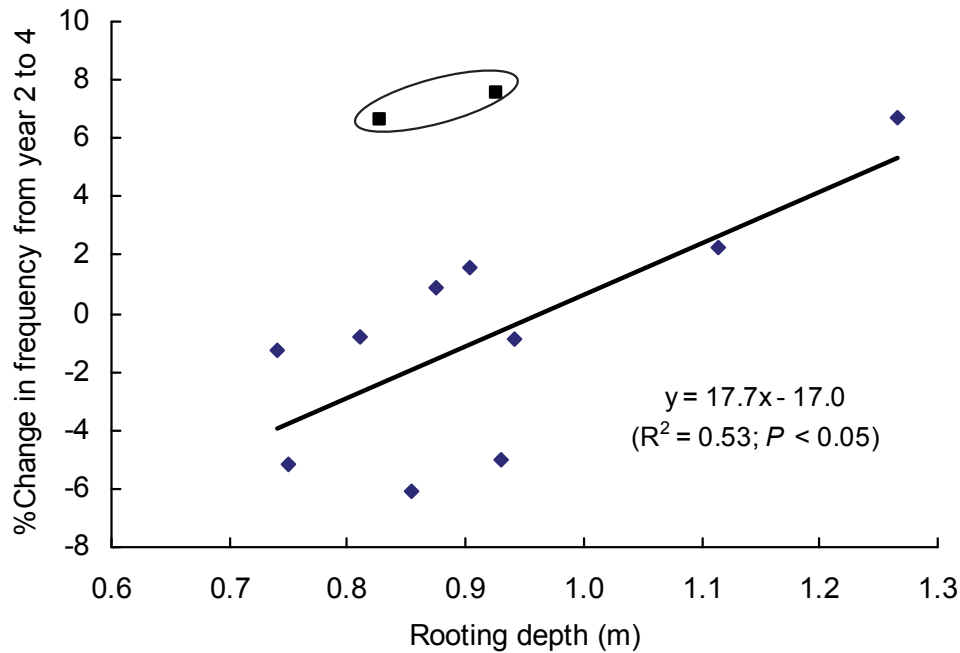


Fig. 2. The relationship between rooting depth and persistence expressed as percentage change in perennial grass frequency from year 2 to year 4 in a perennial grass (see Table 1 for cultivar list) evaluation experiment at Warrak, Victoria, Australia (circled dots are Atlas PG phalaris and Currie cocksfoot; data source: Nie et al., 2008).

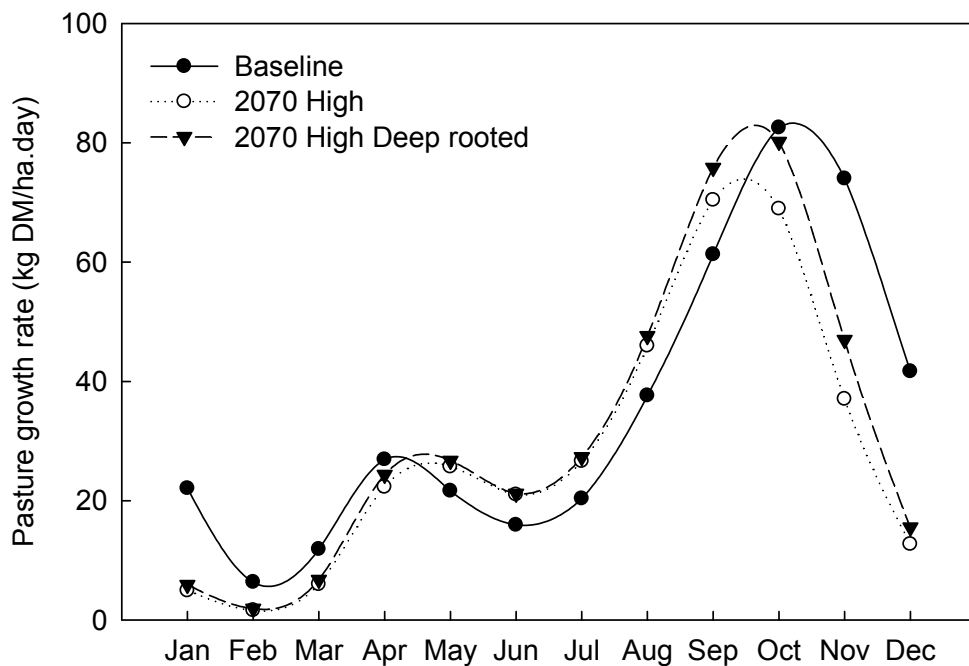


Fig. 3. Predicted pasture growth rate (kg DM/ha.day) at rooting depths of 0.4 m (2070 High) and 0.6 m (2070 High Deep rooted) in a 2070 High climate scenario, and at a depth of 0.4 m in the baseline climate scenario in a high rainfall environment of southern Australia (Adapted from Cullen et al., 2009).

4.2 Summer dormancy

Summer dormancy is an adaptive response of perennial grasses to water and heat stress over summer, which is believed to play a significant role in promoting drought resistance for temperate perennial grasses (Reed et al., 2004; Volaire & Norton, 2006). The mechanisms comprising the summer dormancy trait, the history of the concept and research into dormancy as well as an explanation of how summer dormancy are associated with survival have been reviewed by Volaire & Norton (2006). Based on a set of field protocols and four types of responses – leaf growth in summer, senescence of mature herbage, dehydration of enclosed bases of the youngest leaves and formation of resting organs, they grouped temperate perennial grasses into three distinguished populations: 1) population that maintain active growth under irrigation; 2) population that cease growth completely for a minimum of 4 weeks during summer and 3) population that exhibit reduced growth, associated with partial senescence of foliage, but no dehydration of leaf bases (Voltaire and Norton, 2006). These classifications are more or less associated with the terms that are commonly used for temperate grasses – summer active, summer dormant and summer semi-dormant.

Many studies on summer dormancy trait have been focused on cocksfoot, which has relatively shallower roots, but persists well when grown on stressful soils (light textured) with frequent droughts. In the 1950s, Knight (1960) undertook early studies with a range of cocksfoots of Mediterranean and northern European origin to identify the characteristic signs (e.g. foliage senescence and cessation of growth) of summer dormancy in Mediterranean populations. The results showed that the Mediterranean germplasm had markedly better summer drought survival than the northern European genotypes (Knight, 1960 and 1966). Further studies by Biddiscombe et al. (1977) broadened the range of species and included perennial ryegrass, phalaris and tall fescue as well as cocksfoot. They assessed the effect of summer dormancy on growth and persistence of these species in south-western Western Australia.

Dormancy level in the studies (Biddiscombe et al., 1977) was measured by the ratio, number of new shoots per plant : number of live buds per plant, 12 days after removal of plants in the field and rewatering in late summer (February). The ratio indicated the level of live buds that became active after summer drought – the higher the ratio, the less dormant is the plant. The results from a drier site on a sandy soil showed a strong negative exponential relationship ($R^2 = 0.94$; $P < 0.01$) between summer dormancy ratio and plant survival in the final year (Year 4) (Fig. 4). All cocksfoot and phalaris lines had higher survival rates than the perennial ryegrass lines. Interestingly, the 3 tall fescue lines varied dramatically in final year plant survival, i.e. the cultivar Melik had > 70% of plant survival whereas the other two lines had < 35%. Melik is a highly winter-active cultivar of tall fescue (Reed et al., 2004) whereas the two other lines are summer active. Like rooting depth, summer dormancy did not show benefits on plant survival at a high rainfall site (annual rainfall 1120 mm) in this study.

There has been less information on summer dormancy in tall fescue. Norton et al. (2006) tested two contrasting cultivars of tall fescue, Demeter and Flecha, under drought, full irrigation and simulated mid-summer storm. Though not expressing as high a level of dormancy as was seen in the earlier research with cocksfoot, Flecha exhibited responses associated with partial summer dormancy and used less soil water over summer which helped it to fully survive a severe summer drought and produce a higher post-drought

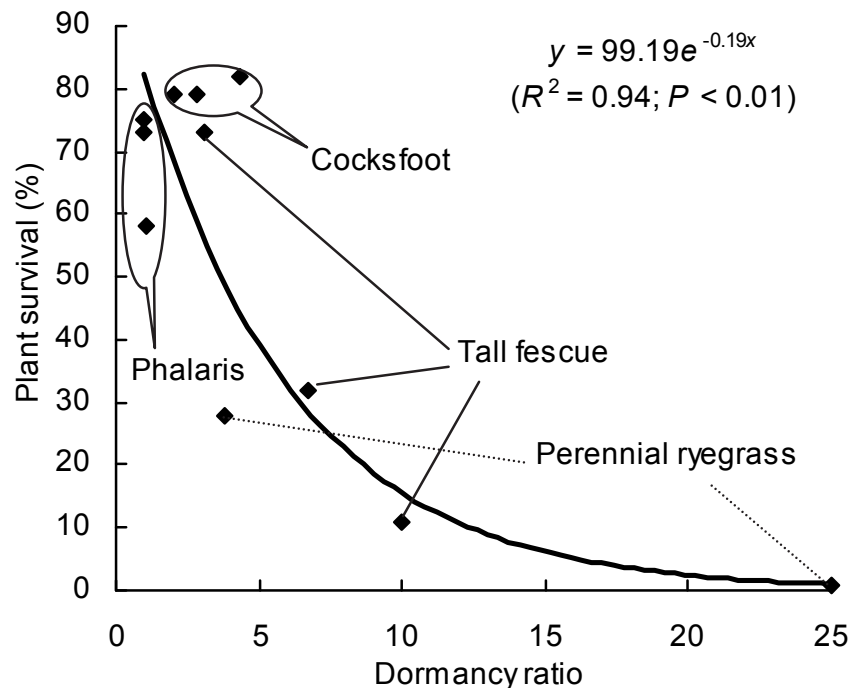


Fig. 4. The relationship between dormancy ratio and plant survival four years after establishment (Data source: Biddiscombe et al., 1977).

autumn yield. In contrast, the summer-active Demeter suffered a 25% loss in basal cover. Just as in the dormant cocksfoot, a high and stable level of dehydrins was observed in Flecha, which may be associated with a membrane stabilising role that these proteins play during drought. Information on summer dormancy in most other perennial grasses in Australia is severely lacking. There is also a trade-off between summer dormancy and herbage production since complete dormancy has been associated mostly with populations of low yield potential (Volaire & Norton, 2006).

4.3 Other traits and mechanisms

Water-soluble carbohydrates provide the most readily available source of energy for grazing animals, and increased WSC concentrations in herbage are considered as an option to alleviate the seasonal deficiencies in the nutritive value of perennial ryegrass (Smith et al., 1998). Apart from their role as nutrients, WSC may have a role in plants' response to drought. Volaire & Lelièvre (1997) found that the total WSC reserves in leaf bases of cocksfoot plants increased by 35% on average during drought. Fructans are the most abundant WSC in some perennial grasses such as cocksfoot and tall fescue, which differ in the degree of polymerisation (DP). High DP fructans are likely to constitute a pool of reserves that is used as substrate as soon as rewatering occurs after moisture stress (Volaire, 1994, 1995). Plants that are adapted to moisture stress (e.g. some of the cocksfoot lines) tend to orientate their metabolism and enzymatic activity towards the constitution of a reserve pool of high DP fructans as soon as drought is imposed (Volaire & Lelièvre, 1997). High DP fructan concentrations are also known to increase in the pseudostem of the perennial ryegrass during drought (Thomas, 1991). The high WSC perennial ryegrass cultivar Aurora had high growth and yield stability during drought and good regrowth after drought (Amin & Thomas, 1996).

Perennial grass plants exhibit different leaf morphological traits which, although more qualitative than quantitative, may well contribute to dehydration avoidance under moisture stress. Bolger et al. (2005) studied a range of native and introduced perennial grasses of south-eastern Australia and observed that the grasses showed different leaf morphological traits at 3 distinct stages of soil drying and plant dehydration. The 3 stages are: Stage I – water is freely available and transpiration from plants leaves remains unaffected as soil water declines; Stage II – soil water availability begins to limit plant uptake, and plant transpiration declines progressively with declining available soil water; Stage III – plant transpiration and stomatal conductance have reached minimal levels, water loss from the plant is constrained and leaves die. In their observation (Bolger et al., 2005), cocksfoot and Kangaroo grass (*Themeda* spp.) folded their leaves whereas wallaby grass (*Austrodanthonia caespitosa*) and *Eragrostis* tightly rolled their leaves at the beginning of Stage III. In contrast, red grass (*Bothriochloa* spp.) and phalaris rapidly shed most of their leaves at the beginning of Stage III, a ‘plastic’ response reducing leaf area and water loss and thereby contributing to dehydration avoidance. Species such as *A. racemosa* did not fold, roll, or shed leaves rapidly at the beginning of Stage III, but accumulated a large amount of cuticular wax on leaves to reduce water loss. *A. caespitosa* rolled its leaves and had a large amount of cuticular wax as well.

An important mechanism that is believed to contribute to the stress tolerance and persistence of perennial ryegrass and tall fescue is the mutualistic association between the perennial grasses and the asymptomatic fungal endophytes, *Neotyphodium lolii* (Latch, Christensen and Samuels) Glenn, Bacon and Hanlin (formerly *Acremonium lolii* Latch, Christensen and Samuels) in perennial ryegrass and *N. coenophialum* (Morgan, Jones and Gams) Glenn, Bacon and Hanlin in tall fescue (Heeswijck & McDonald, 1992; Quigley, 2000). Endophytes can produce alkaloids, of which ergovaline, lolitrem B, and peramine are the most important and therefore have commonly been studied (Rowan et al., 1986). Ergovaline and lolitrem B are toxic to grazing livestock, whereas peramine deters insect attack but has no known effect on domestic animals (Gallagher et al., 1984). The role of endophytes in protecting their grass hosts from insect attack was first reported by Prestidge et al. (1982) in New Zealand, and later in Australia (Heeswijck and McDonald, 1992). Improved resistance of endophyte-infected perennial ryegrass to insects has provided a graphic demonstration of the benefits that endophytes can confer on their host plant. Studies (Heeswijck & McDonald, 1992; Hill et al., 1990; Reed et al., 1985) of the effects on other plant attributes such as seedling establishment and tolerance to water stress showed that the performance of the perennial grasses was enhanced by increased levels of endophyte infection. The greater tolerance of endophyte-infected grasses to drought may result from the effect of the fungus on host-water relations, and it has been suggested that improved osmotic adjustment and turgor maintenance in the basal meristematic and elongating zone of vegetative tillers are involved (West et al., 1990). More information is needed to verify how and to what degree endophytes can contribute to drought tolerance and plant survival in varying environmental conditions. A study by Pecetti et al. (2007) showed that the effect of endophyte presence on persistence was nil in the Mediterranean site and slightly positive in the subcontinental location. They concluded that Mediterranean conditions may be too extreme for any enhancement of persistence to be solely provided by the endophyte, and the physiological adaptation of the grass germplasm was more critical for these environments. The development of novel endophytes in the past decades have aimed to strengthen the ability of endophyte-infected perennial grasses in stress tolerance and resistance to insect attack and reduce toxicity to grazing animals.

5. Development of new perennial grasses

Selection for greater seasonal and yearly productivity, higher nutritive value and lower establishment costs has long been the key breeding objectives for perennial temperate grasses in southern Australia (Oram & Lodge, 2003). This continues to be the major focus in perennial ryegrass improvement for dairy pastures. Over the past decade, however, emphasis has been placed on persistence, adaptation to a wider range of soil conditions, lower toxicity, greater compatibility with legumes, and resistance to pests and diseases, particularly for extensive sheep and cattle grazing pastures due to the changes of climatic conditions experienced in the regions. Waller & Sale (2001) reviewed the persistence problems encountered by perennial ryegrass and concluded that grazing management to encourage seedling recruitment, better genotypes and improved management of soil fertility and pH would be beneficial for high survival of the species. Attempts have also been made to introduce drought resistant traits from natural ryegrass populations persisted in marginal rainfall environments or genes from other persistent plant species such as tall fescue (Humphreys & Pasakinskiene, 1996; Humphreys & Thoma, 1993; Oram & Lodge, 2003).

While perennial ryegrass is highly valuable in establishment, production and feed quality for livestock, it is not generally considered a suitable plant for low rainfall environments in southern Australia. Indeed there are few cultivars of any temperate perennial grasses commercially available for farmers in temperate regions that receive <500 mm annual rainfall (Harris et al., 2008; Reed, 1996). Therefore, attempts have been made to introduce and incorporate genes from plants of low rainfall origin, such as the Mediterranean and North Africa. Australia was one of the first countries to deliberately exploit Mediterranean ecotypes of perennial grasses, due to climatic similarities, the value of pasture plants from the regions and the discovery and domestication of the Mediterranean grass phalaris (Culvenor, 2009; Oram et al., 2009). The adaptation of the perennial temperate grasses into lower rainfall environments has been substantially expanded in Australia by the replacement of early northern European introductions with more drought-hardy and summer-dormant germplasm from Mediterranean regions (Culvenor, 2009). A number of cultivars based on Mediterranean ecotypes were released during the 1950s to the 1970s. For example, Sirocco phalaris was released after selection of a Moroccan accession for seed production (Oram, 1990). Currie cocksfoot selected from an Algerian accession was released in 1958.

Recent emphasis on persistence under low and variable rainfall conditions in southern Australia has seen an increased exploitation of more summer-dormant *hispanic* cocksfoot germplasm. Two new commercial cultivars, Sendace and Uplands, based on *hispanica* accessions collected in Spain were released for drought-prone environments (Hurst and Hall, 2005a,b). More recently (2004 - 2008), work has been conducted in Victoria and northern NSW, to develop improved cultivars of cocksfoot and tall fescue for medium to low rainfall environments of southern Australia. Four elite cocksfoot lines of fine- to very fine-leaved *hispanic* type were developed for further evaluation (Harris et al., 2008). These lines showed excellent persistence and yielded 34 to 40% higher than Currie, the commonly sown cocksfoot cultivar, following a severe summer drought period in 2006 (e.g. 270 mm annual rainfall at a site in Victoria). Experimental varieties of tall fescue based on Sardinian accessions with good summer and winter production and persistence, and a separate variety based on northern African accessions that were highly persistent but retained green leaf over summer on the North-West Slopes of NSW, were also selected in this project (Harris et al., 2008). Further evaluation of these lines has been undertaken to verify their adaptation and persistence across multiple regions in Victoria and NSW.

6. Deferred grazing strategies to improve the resilience of Australian native grasses

Recent recognition of the value of native grass pastures, and their drought resistance and ability to grow in infertile or acidic soils, has led to the selection and release of cultivars in several species (Garden et al., 1996; Lodge, 1996; Oram & Lodge, 2003). In practice, however, native grasses have been largely ignored for sown pastures in Australia, because of the superiority of exotic improved grasses in high-input livestock grazing systems, the biased comparisons of native and introduced pastures (Johnston et al., 1999), and the difficulties in achieving large-scale seed production and successful pasture establishment of native grasses. Native grasses are primarily distributed in areas with low fertility and acidic soils and marginal land classes such as steep hill country where overgrazing, land degradation and climate change impacts have resulted in low groundcover by pasture plant over summer and autumn. These not only have a significant economic (e.g. lack of green feed and low stocking rate) but also environmental impact (e.g. soil/nutrient runoff, recharge and loss of biodiversity) on the grazing industries in southern Australia (Nie et al., 2009).

While it is not currently practical to sow native grasses on a large scale, it is beneficial and critical to develop management strategies to rehabilitate degraded native pastures where native grass population is low (<30%). Over the past decades, a number of studies (e.g. Garden et al., 2000; Nie & Zollinger, 2008) have been undertaken in southern Australia to look into management strategies, grazing management in particular, for the restoration of native grasses. The studies have been focused on three mechanisms that can lead to success: 1) seedling recruitment of native grasses; 2) spread of existing native grass plants; and 3) stronger competition of native grasses with other species (either through seeds or plants). A management option that can promote one or all of the three is deferred grazing that matches the timing of grazing or resting of a pasture to an appropriate growth stage of the pasture grasses (Nie & Mitchell, 2006). For instance, withholding grazing from mid-spring to mid-summer allows desirable perennial plants to set seed and conserve energy, leading to higher recruitment rates of new plants and tillers in autumn and winter. Grazing heavily after annual grass stem elongation but before seed head emergence, followed by resting over spring and summer, will increase the amount of seed produced by perennials while reducing the seed by annuals. A series of experiments have been conducted to develop deferred grazing strategies for native grass restoration on marginal land classes (Nie & Mitchell, 2006; Nie & Zollinger, 2008; Nie et al., 2009). Key results are summarised below.

6.1 Types of deferred grazing

There are several types of deferred grazing which have been designed to achieve different management targets (Nie & Mitchell, 2006). The higher the proportion of desirable native species, the more effective the deferred grazing will be in the restoration process.

6.1.1 Long-term deferred grazing

Long-term deferred grazing involves no defoliation from October to the autumn break (the first significant rainfall event of the autumn/winter growing season) in the following year to build up the soil seed reserves and moisture and restore ground cover by perennial species. This strategy aims to rehabilitate degraded paddocks with low percentage of perennial species (e.g. 5-10%) quickly and effectively.

6.1.2 Short-term deferred grazing

Short-term deferred grazing involves no defoliation between October and January each year, aiming to increase soil seed reserves and plant population density, and to use feed in mid summer when there is generally a feed shortage. In addition, this treatment may reduce fire risk by grazing long grasses down in early summer.

6.1.3 Optimised deferred grazing

With optimised deferred grazing, the withholding time from grazing depends on morphological development of the pasture plants. This deferred grazing starts after annual grass stems elongate but before seed heads emerge so that the growing points of annual grass plants can be effectively removed by grazing. The completion of this grazing strategy depends on pasture conditions (seed set, growth and herbage on offer), generally from late summer to early autumn. This strategy aims to reduce the amount of seed produced by annual grasses and alter pasture composition – lifting the proportion of perennials while suppressing the annual grasses through seed production.

6.1.4 Timed grazing

Timed grazing is an alternative form of the long-term deferred grazing. It is used to build up the soil seed reserve, restore ground cover and recruit new plants. Pasture is grazed using a large mob of sheep greater than 100 sheep/ha over a short grazing period ranging from 10 to 20 days depending on size of paddock, followed by a resting period up to 130 days. This strategy targets the rehabilitation of much degraded paddocks with a very low percentage of desirable species (e.g. ~5%).

In addition, strategic management of pastures can be combined with all types of deferred grazing to deliver the best outcomes. This is often referred to as strategic deferred grazing. For instance, onion grass (*Romulea rosea*) control and fertiliser application can be applied following optimised deferred grazing in an onion grass infested paddock, which may greatly increase the yield and nutritive value of pastures.

6.2 Key impacts of deferred grazing

6.2.1 Soil seed reserve

Soil seed reserve is the number of seeds in topsoil (0 – 3 cm) measured in autumn (Nie & Mitchell, 2006). It is an indication of seed production from a grazing system in the previous seasons. The germinated seed population (an estimation of soil seed reserve) of perennial and annual grasses, two major species categories in a hill pasture, varied greatly under different grazing regimes (Fig. 5). Long-term, short-term and optimised deferred grazing produced 637 – 1850 perennial grass seeds/m² whereas set stocking had 570 seeds/m². Optimised deferred grazing was the most effective treatment to reduce annual grass seed production, with the germinated seed population being the lowest among the other grazing regimes.

6.2.2 Plant density

The results from a long-term grazing experiment (Nie & Mitchell, 2006) have shown that deferred grazing regimes significantly increased perennial (predominantly native grasses) and reduced annual grass tiller density (Table 2). However, there were no significant differences in the densities of onion grass, legumes and broadleaf weeds.

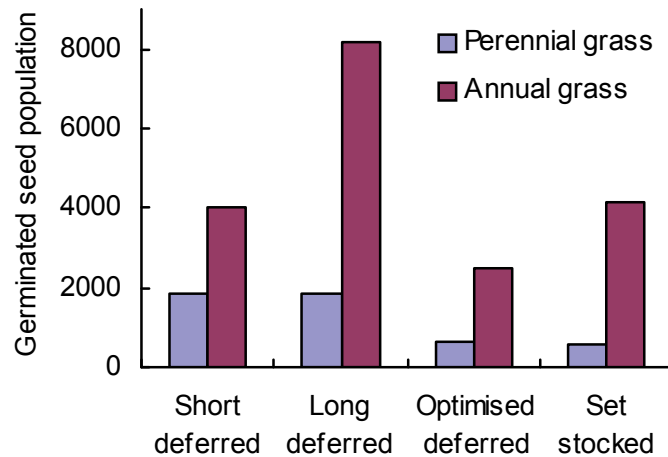


Fig. 5. Germinated seed population (seeds/m²) under short-term, long-term and optimised deferred grazing and set stocking (adapted from Nie & Mitchell, 2006).

Treatment	PG	AG	ONG	Legume	Weed
Short deferred	8338	5396	3159	630	466
Long deferred	9003	4713	3552	460	239
Optimised deferred	9998	2558	3800	411	245
Set stocked	6245	8890	4786	681	248

Table 2. Mean plant density (tillers or plants/m²) of perennial grass (PG), annual grass (AG), onion grass (ONG), legume and broadleaf weed (Weed), under different grazing regimes from a 4-year grazing experiment (adapted from Nie & Mitchell, 2006).

6.2.3 Ground cover

Ground cover remained greater than 70% up to mid January regardless of how the pasture was grazed (Fig. 6). However, when a large amount of dead annual grass under set stocking was removed by grazing from January to March, ground cover declined dramatically, before increasing in autumn (April/May) after some rainfall. Ground cover was consistently higher with all deferred grazing regimes due to limitation of grazing over summer/autumn and increased perennial native grass population (Nie et al., 2005).

6.2.4 Herbage and animal production

Herbage production under deferred grazing regimes increased by 31 – 66% compared with set stocking, two years after deferred grazing regimes were implemented (Table 3). Overall, deferred grazing treatments increased dry matter digestibility (DMD), crude protein content (CP) and metabolisable energy (ME), but reduced neutral detergent fibre (NDF), in comparison with set stocking. The increases range from 2 – 13% for DMD, 10 – 30% for CP and 4 – 18% for ME. Short-term and long-term deferred grazing reduced NDF by 7% and 3%, respectively, but optimised deferred grazing did not, compared with set stocking. The results largely came from increased density and ground cover by perennial native grasses

under deferred grazing (Nie & Mitchell, 2006). An economic analysis on deferred grazing and other grazing regimes revealed that this management strategy can conservatively increase stocking rates by between 25 to 50% within 3 years on hill country currently carrying less than 8 DSE/ha (J Moll Pers. Comm.).

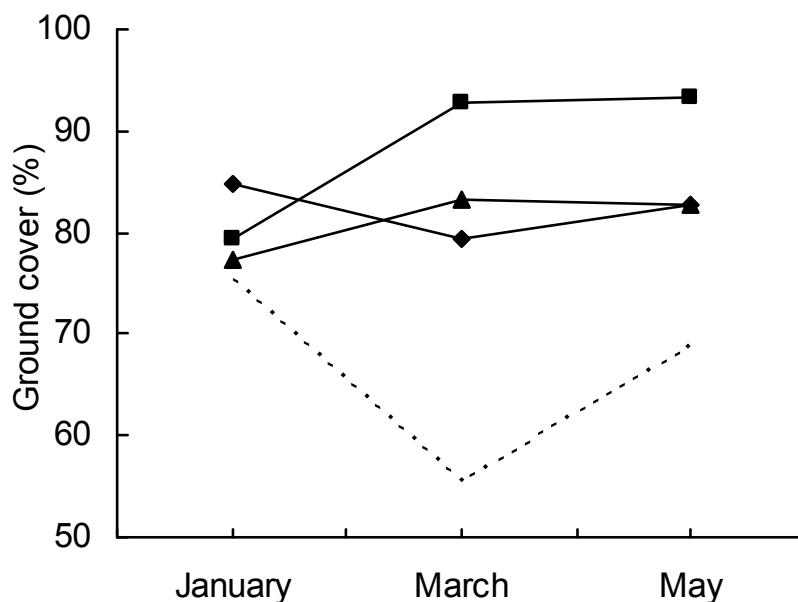


Fig. 6. Ground cover over summer/autumn under short-term deferred grazing (■), long-term deferred grazing (◆), optimised deferred grazing (▲) and set stocking (--) (adapted from Nie et al. 2005).

Treatment	HA	DMD	CP	ME	NDF
Short-term deferred	3500	59.1	12.7	8.6	62.0
Long-term deferred	4141	56.0	11.1	8.0	64.5
Optimised deferred	4433	53.4	10.8	7.6	66.8
Set stocking	2662	52.2	9.8	7.3	66.5

Table 3. Herbage accumulation (HA, kg DM/ha) from July 2005 – July 2006 and mean nutritive value: DMD – dry matter digestibility (%); CP – crude protein (%); ME – metabolisable energy (MJ/kg DM); and NDF – neutral detergent fibre (%) under various grazing regimes (adapted from Nie & Zollinger, 2008).

6.2.5 Plant roots and soil properties

Deferred grazing has a profound effect on below ground plant growth. Root biomass under deferred grazing was increased deeper in the 0-60 cm soil profile compared with set stocking (Nie et al., 1997). With deferred grazing, about 85% of the roots were in the 0-20 cm soil and 15% in the 20-60 cm soil whereas under set stocking over 95% of the total root biomass was in the 0-20 cm soil profile, and only <5% was within 20-60 cm profile. The effect of grazing wet soils has been recognised as a potential problem for soil health. Stock

treading has been shown to increase soil compaction and decrease soil porosity and water infiltration. Management options to reverse compaction without cultivation are desirable. Deferred grazing can reduce soil bulk density by over 10%, increase soil pore size and water movement rate through the removal of stock treading, the growth and subsequent decay of plant roots and the activity of soil fauna, such as earthworms. It also increased the soil moisture content of the 0-10 cm of topsoil (Nie et al., 1997).

7. Conclusion

The significantly lower annual rainfall experienced in southern Australia over the past decade together with long term climate change projections have placed great emphasis on the use of pastures for the grazing industries that are more tolerant to drought and heat stress and persistent under varying climatic and soil conditions. Perennial temperate grasses, both improved exotic and native species, are the key components of pastures for livestock grazing in southern Australia. The four commonly sown improved perennial grasses, perennial ryegrass, phalaris, tall fescue and cocksfoot possess intrinsic traits, have different growth patterns and require suitable environmental conditions to be productive and persistent. Adaptive traits such as rooting depth and summer dormancy have been exploited to develop new cultivars; however, the research has been focused on limited traits and species (e.g. summer dormancy for cocksfoot) and there is a need to expand the breadth of research in term of species, their adaptive traits and technologies to define the traits. Unlike improved exotic perennial grasses, there has been little research on the adaptive traits and plant development for Australian native grasses, although they have evolved in Australia for millions of years and are well adapted to the soil and climate. Nevertheless, recent studies in southern Australia have developed grazing management strategies to restore degraded native pastures. The results have demonstrated the economical and environmental benefits of using deferred grazing to rejuvenate native grasses to adapt to edaphically and climatically stressed landscapes.

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This book provides an interdisciplinary view of how to prepare the ecological and socio-economic systems to the reality of climate change. Scientifically sound tools are needed to predict its effects on regional, rather than global, scales, as it is the level at which socio-economic plans are designed and natural ecosystem reacts. The first section of this book describes a series of methods and models to downscale the global predictions of climate change, estimate its effects on biophysical systems and monitor the changes as they occur. To reduce the magnitude of these changes, new ways of economic activity must be implemented. The second section of this book explores different options to reduce greenhouse emissions from activities such as forestry, industry and urban development. However, it is becoming increasingly clear that climate change can be minimized, but not avoided, and therefore the socio-economic systems around the world will have to adapt to the new conditions to reduce the adverse impacts to the minimum. The last section of this book explores some options for adaptation.

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