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Phosphorus fertiliser management for pastures based on native grasses in south-eastern Australia

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Abstract. Approximately 3.1 Mha (22%) of the agricultural area of south-eastern Australia can be classified as native pasture. There is the assumption that, owing to the widespread occurrence of low-fertility soils in Australia, native grass species do not respond to increased phosphorus (P) fertility. Currently, there are no industry recommendations of target soil-test P values for native-grass-based pastures. This paper reviews the responses of perennial native pasture species endemic to south-eastern Australia to P application in controlled environments, surveys, replicated experiments and paired-paddock trials. Eighty-seven site-years of trial data where different levels of P were applied, conducted over the last two decades, on native-based pastures in south-eastern Australia are reviewed. Data indicate that application of P fertilisers to native grass pastures can increase dry matter (DM) production and maintain pasture stability. However, minimum targets for herbage mass (800 kg DM/ha) and groundcover (80%) are required to ensure persistence of perennial native grasses. Stocking rates also need to match carrying capacity of the pasture. Based on previous research, we recommend target soil-test (Olsen; 0–10 cm) P levels for fertility-tolerant native grass pastures, based on *Microlaena stipoides*, *Rytidosperma caespitosum*, *R. fulvum*, *R. richardsonii*, *R. duttonianum* and *R. racemosum*, of 10–13 mg/kg, whereas for pastures based on fertility-intolerant species such as *Themeda triandra*, lower levels of <6 mg/kg are required to ensure botanical stability.

Additional keywords: *Bothriochloa*, kangaroo grass, red grass, *Themeda*, weeping grass, wallaby grass.

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Introduction

The term 'native pasture' is used by primary producers to describe any pasture that has not been sown, even if it contains few, if any, genuine native species (Mokany *et al*. 2006). It is synonymous with the terms 'naturalised pasture' and 'native grassland', and describes grazing environments dominated by native grasses. This paper uses the commonly accepted definition of a native pasture being 'any pasture in which native grasses are the main perennial species' (Crosthwaite and Malcolm 2001). This covers a broad range of pastures, from those dominated by introduced weeds of low fertility, to those dominated by native species but containing some non-native annual legumes and grasses (Virgona 2006). This definition also covers those situations where sown introduced pastures have been re-invaded by native species that subsequently become the dominant perennial species (Garden *et al*. 2001). Over 1200 species of grass are considered native to Australia (Mason *et al*. 2003).

Within southern Australia, over the last 150 years there has been considerable change in landscapes because of grazing, fertiliser application, and either the accidental or deliberate introduction of species (Garden and Bolger 2001). This focus of this paper is south-eastern Australia, defined as temperate perennial pasture and temperate perennial grass–annual legume pasture zones (Moore 1970). These areas generally have high rainfall (>600 mm annual average rainfall) that is predominantly winter dominant. Approximately 3.1 Mha (22%) of this pastoral zone of south-eastern Australia can be classified as native pasture (Hill *et al*. 1999). Native pastures within these regions play a significant role in wool production systems (Michalk *et al*. 2003; Donald 2012). Much of this area has soils that are shallow, low in phosphorus (P), acidic (pH_{CaCl2} <5.5) and are considered non-arable (Simpson and Langford 1996*b*) and therefore unsuitable for the sowing of introduced species. It should not be assumed that the widespread occurrence of low soil fertility in Australia precludes the occurrence of highly productive native species, or native species that have high P requirements (Waddell *et al*. 2016).

Within native pastures, composition can vary widely because most native pastures are a mix of species. The paper focuses on areas of native pastures in south-eastern Australia where subterranean clover (*Trifolium subterraneum* L.) is the dominant legume. Within these broad pasture types, a wide range of responsiveness to P fertiliser can be expected, as well as varying tolerances to the additional grazing pressure required to utilise any additional feed grown. We review evidence from a variety of experimental approaches including controlled environments, surveys and replicated field experiments undertaken during the last two decades on response of native pasture to P fertilisation. We test the hypothesis that fertilising native pastures in south-eastern Australia with superphosphate is both profitable and sustainable in the long-term, provided certain conditions are met.

Associations between soil fertility and native grass species

Surveys of native pasture have shown that the predominance of key native grass species is related to soil fertility. In a survey of the composition of grazed pasture on the Tablelands of southern New South Wales (NSW), Garden *et al*. (2001) found that the proportions of *Rytidosperma* Steud. spp. and *Microlaena stipoides* (Labill.) R.Br. increased with superphosphate application rate, whereas *Themeda triandra* Forssk. decreased with increasing P fertiliser application. In turn, soils with *Rytidosperma* spp. were associated with high plant available P levels but the opposite was found for *T. triandra*.

In the Victorian Upper Murray, *M. stipoides* was found at 10 sites, with soil-test Olsen P values ranging from 3.7 to 11 mg/kg (Allan and Whalley 2004), indicating an ability to survive at low to medium fertility levels. All sites had an extremely acid topsoil, with pH_{CaCl2} ranging from 4.0 to 4.6.

Native grasses were collected from 210 sites in NSW and Victoria as part of the Low Input Grasses Useful in Limiting Environments (LIGULE) project (Johnston *et al*. 2001), and species occurrence was related to soil P and pH (Fig. 1). *Microlaena stipoides* was found at both low and high P fertility sites, *Rytidosperma* spp. were found at acidic and alkaline pH levels, whereas *Bothriochloa macra* (Steud.) S.T. Blake and *T. triandra* were found mainly at low P fertility and sites with acid topsoils (Fig. 1). The collection sites were mainly along public roadsides where fertiliser is unlikely to have been applied, with 75% of sites having an Olsen P values <8.5 mg P/kg.

A survey conducted in 2004 of 59 randomly selected farms (532 sites) in southern NSW and north-eastern Victoria indicated that although native grasses were commonly found in low-input paddocks, they were rarely dominant (ML Mitchell, unpubl. data). This survey collected data on the occurrence and position of native grasses in the landscape. The region surveyed is bounded by the 550–700 mm isohyets, in permanently grazed landscape. Once on farm, paddock selection was based on areas that the landholder would not or could not sow to introduced perennial species. The survey was undertaken over the summer of 2003–04. The range of soil conditions, Colwell P and pH_{CaCl2} for *B. macra*, *Rytidosperma*, *M. stipoides* and *T. triandra* are shown in Fig. 2. The sites surveyed in this study were on farm, and therefore some had a history of fertiliser application. *Microlaena stipoides* was found at 19% of sites (102 sites), where the median Colwell P was 21.3 mg/kg (Fig. 2*a*). *Bothriochloa macra* was found at 53% of sites (283 sites), and its median pH_{CaCl2} was 5.2 (Fig. 2*b*).

In a collection of 28 natural populations of *Rytidosperma* spp. in Central West NSW, *R. bipartitum* (Link) A.M. Humphreys & H.P.Linder, *R. caespitosum* (Gaudich.) Connor & Edgar, *R. erianthum* (Lindl.) Connor & Edgar, *R. fulvum* (Vickery) A.M.Humphreys & H.P.Linder and *R. setaceum* (R.Br.) Connor & Edgar were all recorded from sites across a broad range of soil pH (pH_{CaCl2} 5.0–8.5) (Waters *et al*. 2009). By contrast, *R. erianthum* was recorded only at sites with a narrower pH range (pH_{CaCl2} 5.2 to 6.8).

In a spatially diverse landscape, the dominant native grass species may be an indicator of production potential. At Orange, in central NSW, higher quality species (in terms of crude protein and digestibility) such as *M. stipoides* and subterranean clover were more prevalent on the lower slopes and in areas with deeper soils and a higher production potential, whereas the rocky upper slopes were dominated by *Rytidosperma* spp. and had lower production potential (Badgery *et al*. 2013; Badgery 2017), with

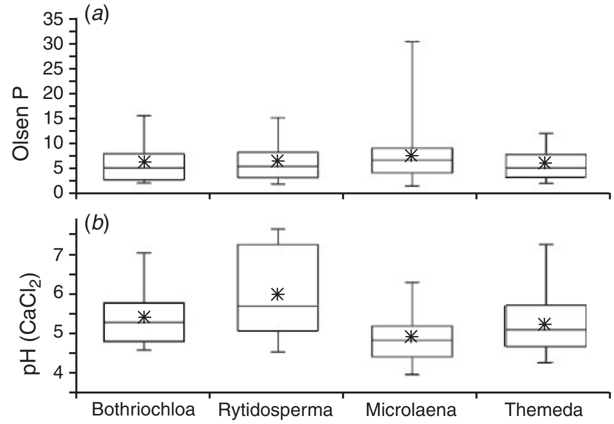

Fig. 1. Box and whisker diagram showing soil test (0–10 cm) characteristics for field collection sites associated with *Bothriochloa macra* (number of collection locations (n) = 39), *Rytidosperma* spp. (n = 143), *Microlaena stipoides* (n = 38) and *Themeda triandra* (n = 64): (*a*) Olsen P (mg/kg), (b) pH in $CaCl_2$. The box range shows 25–75 percentiles, whiskers range shows 5–95 percentiles and asterisk represents the mean. Source data: Johnston *et al*. (2001).

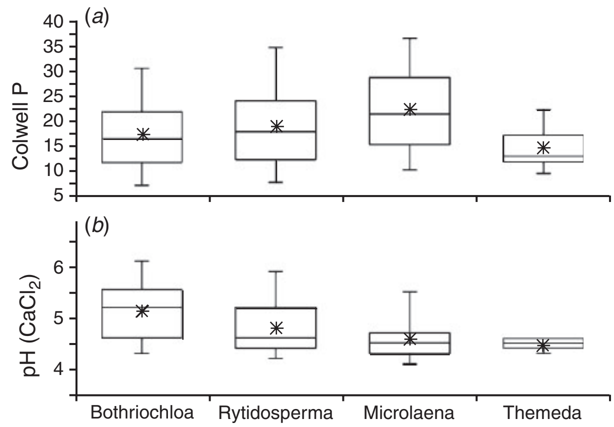

Fig. 2. Box and whisker diagram showing soil test (0–10 cm) characteristics for field survey conditions for *Bothriochloa macra* (number of collection locations (n) = 283), *Rytidosperma* spp. (n = 294), *Microlaena stipoides* (n = 102) and *Themeda triandra* (n = 5): (*a*) Colwell P (mg/kg), (*b*) pH in $CaCl_2$. The box range shows 25–75 percentiles, whiskers range shows 5–95 percentiles and asterisk represents the mean. Source data: ML Mitchell, unpubl. data.

differences related to soil type and water-holding capacity. The low production zone on the upper slopes had aboveground net primary production of 4.6 t dry matter (DM)/ha.year from a plant-available water store of 45 mm, whereas the high production zone on the lower slopes produced 9.9 t DM/ha.year from a water store of 65 mm (Badgery *et al*. 2013; Badgery 2017). This difference in production occurred despite higher P fertility on the upper slopes (Colwell P: 55 *v.* 21 mg/kg), which was likely caused by sheep transferring P to the upper slopes. These results indicated that fertiliser should be applied to the parts of the landscape that are responsive to P based on soil tests. This is the same principle used currently for best management practices in introduced pasture (Simpson and Langford 1996*a*).

Seventeen farms in central Victoria were surveyed by Dorrough *et al*. (2011) to create a predictive model that linked species response with livestock density and available P. The authors concluded that *Rytidosperma* spp. and *T. triandra* may be intolerant of high levels of P fertility, whereas *M. stipoides* was considered moderately tolerant of a range of soil plant-available P concentrations. However, it is unclear whether the authors meant that the grasses were intolerant of high soil P levels or were adversely affected by increased interspecific competition in high-P soils.

Which species are more responsive to added P?

Native grass species vary in their relative responsiveness to P, as indicated by the response data (Table 1). Within *Rytidosperma* spp., there is a considerable range in the growth response to additions of P fertiliser. *Rytidosperma erianthum* and *R. pilosum* (R.Br.) Connor & Edgar had lower P fertiliser requirements to achieve 90% maximum yield than *R. duttonianum* (Cashmore) Connor & Edgar and *R. richardsonii* (Cashmore) Connor & Edgar. Some of this may be within-species genetic variation, because the plant material in all experiments was unselected.

In Australia there are ~40 different species of *Rytidosperma* (Linder *et al*. 2010). To date, all species tested show a positive response to the addition of nitrogen (N) and P fertiliser; however, there is a considerable range of growth responses (Bolger and Garden 1999; Waddell *et al*. 2016). Relative to growth at the highest P application rate, the nil treatment ranged from ~25% of maximum yield for *R. carphoides* (F.Muell. ex Benth.) Connor & Edgar, *R. duttonianum* and *R. pilosum* to ~46% for *R. fulvum* and *R. richardsonii* (Bolger and Garden 1999; Bolger *et al*. 2001). Waddell *et al*. (2016) found that of nine species examined, three (*R. duttonianum*, *R. racemosum* (R.Br.) Connor & Edgar and *R. richardsonii*) responded to increased levels of P, with shoot yields similar to perennial ryegrass (*Lolium perenne* L.). Conversely, several species (*R. auriculatum* (J.M.Black) Connor & Edgar, *R. carphoides* and *R. erianthum*) had relatively slow biomass accumulation rates and did not respond to higher rates of P application (Waddell *et al*. 2016). These substantial differences in P response across species within the *Rytidosperma* genus may make it difficult for landholders to determine whether their pastures are likely to respond to P fertiliser. If landholder could identify which *Rytidosperma* species are present in their pastures, then they would be able to identify pastures, or areas within pastures, likely to respond to P fertiliser, and pastures with potential to shift to a more

Table 1. Responses of a range of native grasses to fertiliser phosphorus (P) in pot experiments

+, Significant positive effect on herbage production; –, no significant effect on herbage production. Ranking of species within each experiment is based on the P application rate at which 90% of maximum growth occurred (where this was measured), where ranking 1 means the lowest amount of P applied to reach 90% of maximum growth

Species	P response	Ranking within study	Reference
Austrostipa mollis	–		Nie *et al*. 2009
Bothriochloa macra	–		Nie *et al*. 2009
B. macra	+		Lodge 1979
Chloris truncata	+		Lodge 1979
Microlaena stipoides	–		Nie *et al*. 2009
M. stipoides	+	1 (of 2)	Clark *et al*. 2014
Rytidosperma auriculatum	+	3 (of 8)	Bolger and Garden 1999
R. auriculatum	+	6 (of 9)	Waddell *et al*. 2016
R. bipartitum	–		Nie *et al*. 2009
R. carphoides	+	1 (of 8)	Bolger and Garden 1999
R. carphoides	+	3 (of 9)	Waddell *et al*. 2016
R. duttonianum	+	4 (of 8)	Bolger and Garden 1999
R. duttonianum	+	2 (of 9)	Waddell *et al*. 2016
R. erianthum	+	8 (of 8)	Bolger and Garden 1999
R. erianthum	+	9 (of 9)	Waddell *et al*. 2016
R. fulvum	+	6 (of 8)	Bolger and Garden 1999
R. fulvum	+	4 (of 9)	Waddell *et al*. 2016
R. pilosum	+	5 (of 8)	Bolger and Garden 1999
R. pilosum	+	8 (of 9)	Waddell *et al*. 2016
R. racemosum	+	2 (of 8)	Bolger and Garden 1999
R. racemosum	+	1 (of 9)	Waddell *et al*. 2016
R. richardsonii	+	7 (of 8)	Bolger and Garden 1999
R. richardsonii	+	5 (of 9)	Waddell *et al*. 2016
R. setaceum	–		Nie *et al*. 2009
R. setaceum	+	7 (of 9)	Waddell *et al*. 2016
Themeda triandra	–		Nie *et al*. 2009
T. triandra	+	2 (of 2)	Clark *et al*. 2014

productive species composition after fertiliser applications. Species within the genus *Rytidosperma* are particularly difficult to identify by leaf and even floral characteristics (even for experts). It has long been recognised that among landholders the level of native grass knowledge and identification skills is low (Simpson and Langford 1996*b*; Garden *et al*. 2000; Andrew 2008). A practitioner-friendly identification tool involving DNA-based test has been suggested by Waddell *et al*. (2016), and would greatly assist *Rytidosperma* pasture management. Therefore, to improve the management of *Rytidosperma* pastures, future action and research needs to be undertaken in (*i*) farmer education, and (*ii*) tools to assist native grass identification.

Rytidosperma richardsonii uses root phosphatase and citric acid exudations to increase P uptake from otherwise unavailable pools of soil P, and these processes are enhanced under low-P conditions (Gifford *et al*. 1995). Whether these mechanisms operate in other species of *Rytidosperma* is unknown. Many native species tolerant of infertile soils are intrinsically slow-growing species and, hence, better adapted to nutrient-poor habitats (Grime and Hunt 1975; Lambers and Poorter 1992). However, these species are not suited to the high yield goals of many managed agricultural systems.

These varying P responses illustrate the benefits of a more precise definition of native pastures, and instead should be referred to by the dominant perennial grass species, such as a '*Microlaena stipoides* pasture'. This naming is consistent with how introduced perennial pastures are reported (e.g. a 'phalaris pasture' or 'perennial ryegrass pasture').

Current recommendations for native pasture management

Generic management guidelines for native pasture were produced from experimental research (Garden *et al*. 2003*a*, 2007; Sargeant *et al*. 2009). The focus of these research programs was on grazing rather than fertiliser management. These recommendations can be summarised as:

- Identify native grasses and invasive annual species.
- Use rotational or cell grazing.
- Target minimum herbage mass (800 kg DM/ha) and groundcover (80%).
- In spring apply extra grazing pressure to ensure subterranean clover does not smother native grasses.
- Reduce grazing pressure in summer to allow seedset.
- In late summer retain plant litter to minimise bare ground.

These recommendations, in the most part, are the same as those recommended for a sown introduced perennial pasture. Although fertility and grazing management guidelines for sown pasture can be applied confidently across a wide range of agro-climatic situations, this is not the case for native pasture because of the wider range of species present and the diversity of environments in which they occur. The management recommendations are in place to protect the groundcover and the perennial plant while enabling animal production.

Fertilising native pasture

In native pastures, when fertiliser is applied it is almost exclusively applied as single superphosphate. This is because the limiting nutrients are first P then sulfur. Within these pastures, the winter-growing annual legume component (e.g. subterranean clover) typically provides the N. These legumes provide most of the response to P, and the native perennial grass provides sward stability.

Fertiliser is a key input for increasing the DM production and profitability of native pasture (Michalk *et al*. 2003). A range of replicated field experiments conducted in south-eastern Australia examining native pasture response to fertiliser is summarised in Table 2. From these experiments there is evidence that native pasture productivity can be increased with the addition of P fertiliser. Many factors affect fertiliser response, including pasture type, environment, soil type and livestock enterprise. Many published experiments have been conducted for <5 years (Garden *et al*. 2003*b*; Dowling *et al*. 2006; Nie and Zollinger 2012), with most including a period of drought. These replicated experiments have been complemented by paired-paddock trials that have been monitored for longer periods (Friend *et al*. 2001*a*, 2001*b*; Powells *et al*. 2013), including one up to 25 years (Graham 2006).

Current P calculators do not account for pasture type (e.g. Simpson *et al*. 2009; Holbrook Landcare Network 2013), and the general rule is to apply P fertiliser first to pasture that includes potentially P-responsive introduced species, but no other guidance is provided for pasture with a high proportion of native species. It is the critical soil-nutrient requirement of the legume component within the pasture that determines nutrient requirements because legumes typically have higher P requirements than the grasses in the sward (Gourley *et al*. 2019). Grass–legume pastures are fertilised to meet the legume's higher P requirement, because legume N_2 fixation ultimately drives pasture productivity (Sandral *et al*. 2019). It is because P management is determined by the high P requirement of the legumes in a pasture that the calculators presently do not differentiate between 'pasture types'.

Findings from 87 site-years of grazing experiments on native pastures are summarised in Table 2, and show that pastures with a base of fertility-tolerant native grasses such as *M. stipoides*, *B. macra*, *R. caespitosum*, *R. fulvum*, *R. richardsonii*, *R. duttonianum* and *R. racemosum* were able to maintain their basal cover in the high-fertility treatment at an Olsen P level of 10–13 mg/kg, while also showing production benefits such as higher carrying capacity. However, there is insufficient evidence to extend these findings to pastures with a base of fertility-intolerant species such as *T. triandra*, *R. carphoides*, *R. auriculatum* and *R. erianthum*, and we recommend a lower target fertility of <6 mg/kg where these are the dominant species to avoid the risk that these grasses are displaced by other more P-responsive grasses and/or legumes (Bolger and Garden 1999; Garden *et al*. 2003*b*; Dorrough *et al*. 2011; Waddell *et al*. 2016). From the data presented in Table 2, it is evident that the 2% native grass content at the Harrogate site was too low to assess whether it was tolerant of the higher fertility level (Garden *et al*. 2003*b*). Soil-test P targets are more useful to landholders than recommendations of quantities of P to apply because they are applicable across different soil types (e.g. Gourley *et al*. 2019) and allow landholders to adjust P application rates according to the current soil-test P status of paddocks (e.g. Simpson *et al*. 2009; Holbrook Landcare Network 2013). Increased use of this current, best practice approach to soil P fertility management (i.e. use of soil testing and soil-test targets for management) will ultimately help to demystify the use of P fertilisers on native-grass-based pastures.

The application of P fertiliser may have a destabilising effect on the composition of native pastures. If the growth of annual legumes and grasses is stimulated by P application without sufficient additional grazing pressure in spring, annuals may outcompete the native perennial grasses (Garden *et al*. 2003*b*). The main P fertiliser recommendation to date has been to make the changes gradually over many years, using small annual applications of P fertiliser rather than a single large application (Simpson and Langford 1996*a*; Garden *et al*. 2003*a*). Recommended rates of superphosphate commonly applied to native pastures range between 4 and 13 kg P/ha.year (Lodge and Roberts 1979; Garden *et al*. 2003*b*; Lodge *et al*. 2003*a*, 2003*b*). Application rates up to 50 kg P/ha.year have been used in experiments (Table 2). These rates are rather meaningless without context. The preferred management is to know the starting soil P fertility, set a viable target for management and work towards it with modest applications of fertiliser appropriate for the species, and plan an increase in livestock numbers as feed supply increases so that competition can be managed

Table 2. Final soil-test P levels and outcomes from trials examining native pasture response to fertiliser in the high-rainfall zone of south-eastern Australia

In the source reference, soil-test values were reported only for either the Olsen or Colwell extractant, and corresponding values in the other extractant were calculated according to McCaskill *et al.* (2003), and are shown in italics; for Carcoar, NSW, soil data were reported as Bray for 0–5 cm. All other soil tests were for 0–10 cm soil cores

Location	Main native grass species (basal cover %)	P applied (/ha.year)	Final soil P level (mg/kg)		Response	Trial period	Reference
			Olsen	Colwell			
Ararat, Vic.	*Microlaena*, *Rytidosperma*, *Austrostipa* (23%)	Nil	7	*9*	Fertiliser application increased legume plant density by 60%	2002–2006	Nie and Zollinger 2012; Z Nie, unpubl. data
		50 kg	16	*33*			
Bendigo, Vic.	*Themeda* (64%)	Nil	10	*23*	Remained relatively stable, which may have been due to the limited amount of grazing applied; however, there was no clear effects of treatments	1998–2001	Garden *et al.* 2003*b*
		8.8 kg	?	?			
		22 kg	20	*47*			
Berridale, NSW	*Austrostipa*, *Rytidosperma* (77%)	Nil	*12*	28	Fertiliser applied to increase economic return without compromising stability of the native pasture; 80% increase in carrying capacity	2004–2012	Alcock *et al.* 2012; Powells *et al.* 2013
		11 kg	*15*	34			
Bookham, NSW	*Rytidosperma*, *Microlaena* (18%)	Nil	*3*	7	Over a 25-year period a doubling of stocking rate while maintaining pasture stability	1993–2017	Hill *et al.* 2004; Graham 2006; Graham 2017
	Rytidosperma, *Microlaena* (32%)	7.7 kg	*13*	30			
Bothwell, Tas.	*Rytidosperma*, *Austrostipa*	Nil	5	12	Increase in carrying capacity from 2.8 to 3.8 DSE/ha	1994–2000	Friend *et al.* 2001*a*, 2001*b*
		44 kg	*11*	25			
Bungarby, NSW	*Poa sieberiana* (91%)	Nil	*13*	30	Fertiliser applied to increase economic return without compromising stability of the native pasture; 80% increase in carrying capacity	2004–2012	Alcock *et al.* 2012; Powells *et al.* 2013
		11 kg	*22*	52			
Carcoar, NSW	Native pasture (*Rytidosperma*, *Themeda*, *Bothriochloa*), annual grasses, annual legumes, broadleaf weeds	Nil	*5*	*12*	Fertiliser application increased pasture herbage mass by up to 60%, but most of the response came from annual grasses and legumes during spring	1997–2002	Dowling *et al.* 2006; MR McCaskill, unpubl. data
		47 kg	*12*	*28*			
Chiltern, Vic.	*Microlaena*, *Rytidosperma*, *Austrostipa* (>60%)	Nil	6	14	Pasture production response to higher fertiliser inputs roughly equivalent to the consumption by additional ewes grazed in the higher fertiliser treatment (5 *v.* 3 ewes/ha)	2008–2012	Mitchell *et al.* 2013
		22 kg	12	24			
Harrogate, SA	*Rytidosperma* (2%)	Nil	*11*	25	Wide seasonal fluctuations in annual species with no clear effects of treatments	1998–2001	Garden *et al.* 2003*b*
		12 kg	*12*	30			
Nile, Tas.	*Rytidosperma*, *Microlaena*	Nil	5	12	Doubling of carrying capacity from 2.5 to 6.0 DSE/ha	1995–2000	Friend *et al.* 2001*a*, 2001*b*
		44 kg	*11*	25			
Pawtella, Tas.	*Rytidosperma*, *Poa labillardierei*	Nil	5	12	Doubling of carrying capacity from 3.3 to 6.0 DSE/ha	1995–2000	Friend *et al.* 2001*a*, 2001*b*
		34 kg	*11*	25			
Yass, NSW	*Rytidosperma*	Nil	3	7	Doubling in stocking rate with maximum fertiliser application	1998–2001	Garden *et al.* 2003*b*
		5.5 kg	*4*	9			
		11 kg	*5*	12			
		22 kg	*9*	20			

(e.g. Simpson *et al*. 2009; Holbrook Landcare Network 2013). This approach of a target soil P fertility was successfully used in the Bookham grazing demonstration (Graham 2017).

Seasonal conditions during an experiment may impact pasture stability, with above-average winter and spring rainfall favouring legumes and annual grasses. However, experiments that have run for longer than 3 years indicate that these impacts are either minor or transient (Alcock *et al*. 2012; Graham 2017). Strategic resting from grazing may also lead to greater pasture stability (Hill *et al*. 2004; Alcock *et al*. 2012; Mitchell *et al*. 2013; Badgery *et al*. 2017). In a native pasture at Chiltern, Victoria, with a high density of perennial native species and a low legume content, rotational grazing and fertiliser had limited influence on pasture composition. This lack of composition changes is probably due to the imposition of critical destocking to achieve benchmarks of groundcover (80–90% on hill country) and herbage mass (800 kg DM/ha) (Mitchell *et al*. 2013).

Grazing management of native pasture is focused on protecting the perennial grass component. This contrasts with management of pastures based on introduced perennial grasses such as *Phalaris aquatica* L., where appropriate grazing management also focuses on maintenance of desirable levels of clover (e.g. Warn and McLarty 2001; Chapman *et al*. 2003; Hill *et al*. 2004, 2005).

Studies conducted at several sites over multiple years at a range of locations and across a range of species have reported a doubling of annual DM production from native pasture through the application of non-limiting P fertiliser (Friend *et al*. 2001*a*; Garden *et al*. 2003*b*; Dowling *et al*. 2006). The increased production from the native pasture was not derived from the native grasses present but from the response of the other species (mainly introduced annual legumes and grasses) to application of the P fertiliser (Garden *et al*. 2003*b*; Dowling *et al*. 2006). These results illustrate the importance of increasing stock numbers and the use of grazing to control competition to ensure that the native grass species are not displaced by other, more P-responsive, grasses and/or legumes.

It is hard to separate the response of the native grasses and legumes to P fertiliser application from the grazing-management regime imposed. Native pasture should be managed no differently from introduced pasture when fertilised, with any extra DM grown matched by increased stocking rates (Keys 2001). Grazing management is an important tool in manipulating the botanical composition of native pasture and is essential in P-fertilised pasture to control clover and ensure persistence of native grasses (Friend *et al*. 2001*a*; Dowling *et al*. 2006). The perennial native grass component provides a stabilising function ensuring summer groundcover, pasture DM production from summer rainfall, and uptake of nitrate to minimise nitrate leaching, whereas the clover and annual grass components provide feed of high nutritive value during winter and spring. The challenge in managing such swards is to maintain enough perennial native grass to ensure stability, while providing sufficient bare ground in autumn for the germination of the annual species that provide the productivity during winter and spring.

Paired-paddock demonstration trials indicate that fertilising native pastures to a target soil-P level, while running productive stock, is profitable (Alcock *et al*. 2012; Graham 2017). Higher rates of fertiliser (250 kg single superphosphate/ha.year) applied to a *Rytidosperma*-dominant pasture increased the annuity from AU\$95 or \$134 to \$134 or \$201/ha.year, at district or high-management-skill level, respectively (Barlow *et al*. 2003; Garden *et al*. 2003*b*). Similarly, economic modelling of a Merino enterprise in Tasmania over a 10-year period showed that the average gross margin on fertilised *Rytidosperma*-dominant pasture was \$90/ha, compared with \$54/ha for unfertilised pasture (Friend *et al*. 2001*b*).

Conclusions

Native pastures have a place in the landscape where it is not economic to introduce perennial species, where it is inaccessible or non-arable, or in landscapes where the grasses are the best adapted species (e.g. as evidenced by places where sown pastures have reverted to native grass dominance; Garden *et al*. 2000). Many native species are responsive to P application. Both survey data and long-term paired-paddock trials indicate that the productivity and persistence of native pastures can be increased by higher soil-P levels. However, the target soil-P values are dependent on the dominant native grass species present. We suggest target soil-test (Olsen) P values of 10–13 mg/kg for pastures that are based on the fertility-tolerant native grass species such as *M. stipoides*, *B. macra* and some *Rytidosperma* spp. (*R. caespitosum*, *R. fulvum*, *R. richardsonii*, *R. duttonianum* and *R. racemosum*) are P responsive, but lower target Olsen P values of <6 mg/kg for pastures based on fertility-intolerant native species such as *T. triandra*, *R. carphoides*, *R. auriculatum* and *R. erianthum*. The fertility-tolerant grasses will respond and be competitive against other sward components when the pasture is fertilised to the higher fertility level, whereas the fertility-intolerant/slow-growing species will be outcompeted by responsive species and can, therefore, tolerate only a much lower level of P fertility. The recommendations for pastures based on fertility-tolerant native-grass-based pastures are essentially the same as for pasture based on introduced species, 10–15 mg Olsen P/kg (Simpson *et al*. 2015), 15 mg Olsen P/kg (Gourley *et al*. 2019) and 13 mg P/kg (Sandral *et al*. 2019). Fertilising to keep soil-test P within a target range ensures cost-effective fertiliser use. However, our current knowledge is limited to only a few key native grass species and is based on limited research experiments that have been conducted over short timeframes. To ensure persistence of the fertility-tolerant native grasses at the higher P levels, sheep need to be removed temporarily under conditions of low feed availability should herbage mass fall to 800 kg DM/ha or groundcover to 80%, whereas under conditions of high feed availability, stocking rates need to be increased to match pasture carrying capacity. Again, these recommendations parallel those for protecting the persistence of introduced perennial grasses (Mason *et al*. 2003).

A sound knowledge of species identification is vital for landholders to make more informed decisions. For decades, the importance of landholders being able to identify native species has been highlighted. This is particularly true for *Rytidosperma*. There is a need to improve the terminology used in referring to pastures that contain native species. A more sophisticated approach needs to be fostered, where the dominant native grass is referred to. For example, instead of being referred to as a 'native pasture', it could be a '*Microlaena* pasture'.

Conflicts of interest

The authors declare no conflicts of interest.

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