Factors affecting pasture production in variable landscapes – how does it influence fertiliser use and other management issues?

B. Hackney[A], P. Orchard[B], D. Kemp[C], B. Orchard[B]

[A]Department of Primary Industries, Research Station Drive, Bathurst, NSW, 2795;
[B]Department of Primary Industries, Pine Gully Rd, Wagga Wagga, NSW 2650;
[C]Charles Sturt University, Leeds Parade, Orange, NSW, 2800

Abstract: *This paper reports on the results of a fertiliser response studies on the Central Tablelands and Monaro regions of New South Wales in variable landscape paddocks. Two sites were studied, one on the central Tablelands at Burraga, 80 km south of Bathurst and the second at Jimenbuen on the Monaro, 60 km south-west of Cooma. At each of these sites, fertiliser experiments were located at upper and lower slope positions on a north and south aspect. At both sites, without the addition of fertiliser, south slope positions in the landscape were significantly more productive than those on the north slope.*

Three factors were found to alone or in combination, indicate whether specific areas of the landscape were likely to be responsive to fertiliser addition. These were identification of soil physical limtations, botanical composition limitations (particularly legume content) and soil chemical limitations. This study indicates that adoption of differential approaches to management of topographically diverse landscapes, particularly with respect to fertiliser addition and fencing is warranted.

Key words: phosphorus, aluminium toxicity, soil moisture

Introduction

In Australia, the scientific community have relied heavily on the results of soil testing to indicate whether a pasture paddock is likely to be responsive to the application of fertiliser. In general, phosphorus (P) and sulfur limit pasture productivity and especially the growth of legumes, which are an important source of fixed nitrogen (N) (Whittet 1925; Donald 1965; Henzell 2007). Various models have been developed over time that predict optimum soil available P level where pasture production is unlikely to be limited. Refinements to these models have been made which take into account the P buffering index (PBI) and animal removal of nutrients from the pasture system (Gourley *et al.* 2007; Simpson *et al.* 2009).

Improved targeting of fertiliser use is becoming increasingly important with the rising cost of fertiliser and predictions that P-based fertiliser prices may double again within the next 10–15 years (van Kauwenbergh 2010). While some recent refinements to P requirement models are an important step in increasing the efficiency with which this resource is used, these models still assume uniformity in response to application of fertiliser and there is little capacity for these models to take into account variation in landscape characteristics such as soil depth, moisture holding capacity and aspect. All of these factors can affect botanical composition and therefore the ability of pasture to respond to fertiliser addition. Simpson *et al.* (2009) have factored in some landscape characteristics of slope and its effect on nutrient loss into a P requirement model, based on New Zealand data. More fundamentally, all P requirement models are based on the 'basal nutrient' type of approach to determining P requirement. Traditionally, fertiliser requirement experiments also generally occur in botanically favourable well-balanced pastures, where topography is not variable. How applicable are such results in pasture paddocks where topography, soil type and pasture composition vary and how can we attempt to best manage these landscapes?

In New Zealand, there have been many experiments undertaken in variable landscapes to determine the extent of variation in pasture production and in some cases, response to fertiliser in topographically diverse landscapes (Radcliffe 1982; Gillingham *et al.* 1999). Studies have been undertaken to determine the impact of adopting a strategic approach to fertiliser application in these landscapes, which considers landscape features and response potential. Such changes in management have revealed considerable benefits to overall farm profitability by adopting such management changes.

To date, there has been little research in Australia to determine how variable pasture production and response to fertiliser is in topographically diverse pasture paddocks. Some preliminary research by Hackney and Virgona (2001) on the south-west Slopes of New South Wales (NSW) demonstrated pasture production ranged from 300–9000 kg dry matter (DM)/ha in a topographically variable pasture paddock. Such differences in production potential indicate that the assumption of uniformity of pasture production and therefore response potential to applied fertiliser is likely to be flawed. This paper reports on the results of a fertiliser response studies on the central Tablelands and Monaro regions of NSW in variable landscape paddocks.

Research site locations and design

Two sites were studied, one on the central Tablelands at Burraga, approximately 80 km south of Bathurst and the second at Jimenbuen on the Monaro, approximately 60 km south-west of Cooma. At each of these sites, fertiliser experiments were located at upper and lower slope positions on a north and south aspect [referred to as north upper (NU), north lower (NL), south upper (SU) and south lower (SL)]. At each position in the landscape, single superphosphate was applied at rates equivalent to 0, 10, 20, 40, 60 and 80 kg P/ha each year for three years. Long-term average annual rainfall at the Burraga site was 830 mm. Over the years of the experiment (2001–03) rainfall was 89, 77 and 87% of the long-term average. At Jimenbuen, long-term average annual rainfall was 560 mm and over the years of the experiment it was 110, 95 and 84% of the long-term average.

The sites chosen were native perennial grass based pastures typical of those found in each respective region. The central Tablelands site was a microlaena – (*Microlaena stipoides*) based pasture while the Monaro site was a spear grass – (*Austrostipa bigeniculata*) based pasture. At both sites, subterranean clover (*Trifolium subterraneum*) had been introduced some 30 years earlier during the so-called 'sub and super' era of pasture improvement. Varieties of subterranean clover present at the sites included Mt. Barker and Woogenellup. Both sites were acidic with pH at the Burraga site ranging from 4.4–4.8 across landscape positions. At Jimenbuen, pH ranged from 4.6–4.8 across landscape positions. Aluminium as a percentage of total cation exchange capacity ranged from 8–22% across landscape positions at the Burraga site, and from 4–10% at the Jimenbuen site.

Pasture composition and herbage was assessed using the Botanal technique (Tothill *et al.* 1992) 15 times at the Burraga site over three years and 14 times over three years at the Jimenbuen site. Herbage samples were cut and removed after each assessment.

Results

While the pasture paddocks used in this study were considered to be based on native perennial grasses and an annual, exotic legume, the composition differed significantly across the sites at the commencement of the study (Table 1). In general, the legume component of the pasture was significantly lower on north aspect positions. At the Burraga site, the native grass frequency was significantly lower at the NU position compared with all other positions in the paddock. At Jimenbuen, the highly drought tolerant spear grass was present at higher frequency on the north slope while remnant cocksfoot (*Dactylis glomerata*), a result of pasture sowing in the 1970s, as found only at south slope positions.

Pasture production and fertiliser response

Over the three years of the study, cumulative pasture production ranged from 18.4–31.7 tonnes (t) DM/ha at Burraga and 15.8–19.8 t DM/ha at Jimenbuen, respectively (Figure 1). At both sites, without the addition of fertiliser, south slope positions in the landscape were significantly more productive in terms of total herbage production and legume production, than those on the north slope. (Hackney 2009).

At the Burraga site, despite all positions at both sites having soil available P levels which would indicate they should be responsive to P application, only three of the four positions showed increases in pasture production with addition of fertiliser (Figure 1). At Jimenbuen, only one of the four positions was responsive to the application of fertiliser.

Again at the Burraga site, where responses to application of P occurred, the response was due solely to an increase in legume production, while at Jimenbuen the increase was due to a combination of increased production from both legumes and cocksfoot (data not shown). The increase in pasture production at the Burraga site occurred in spring of all three years and in autumn in the final year of the study. At Jimenbuen, pasture production increased with use of fertiliser only in spring and only in the first year of the study, when seasonal conditions were wetter than average.

Why was pasture production and composition so variable and why were some positions unresponsive to fertiliser application despite having low initial available soil P?

Solar radiation was measured on the north and south slope at both sites. Solar radiation over the period of the study was 8 and 5% higher on the north, compared with the south slope at the Burraga and Jimenbuen sites, respectively. As a result, soil temperature was generally higher for north slope positions. While it might seem that higher soil temperatures would be more favourable for pasture growth, it also means that soils dry out more quickly. At the north slope positions, measurements taken over the duration of this study showed that these landscape positions were either consistently drier and/or had more erratic wetting and drying patterns meaning that sustaining long periods of pasture growth was less likely. Consistency of moisture availability is particularly important for shallow-rooted species such as the annual legumes found at these sites. At both Burraga and Jimenbuen, annual legumes contributed more to overall pasture production on the south slope positions, without fertiliser addition than on the north slope positions and it is likely that the less consistent soil moisture conditions had contributed to lower populations of legumes at north slope positions. Despite both paddocks having had subterranean clover sown introduced uniformly across the paddocks decades ago, populations were lower on the north slope, particularly at Jimenbuen than on the south slope. Similar results have been reported in New Zealand studies. An adequate legume population is essential in realising an increase in pasture production in response to P fertiliser addition. Grasses will respond to application of P fertiliser, but only up to the limit of N availability (Wilson and Haydock 1971).

Nutrient responsive locations had moderate to high initial populations of legumes (Table

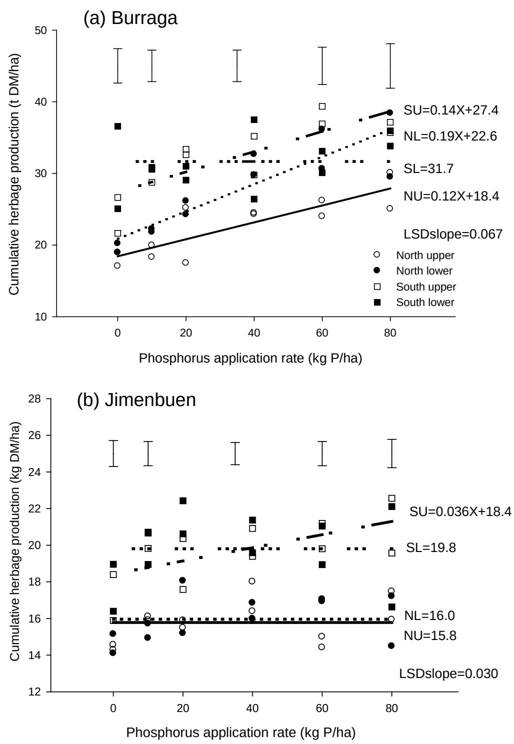

Figure 1. Cumulative herbage production over three years at north upper (NU), north lower (NL), south upper (SU) and south lower (SL) slope positions at various rates of P application (applied as single superphosphate) at (*a*) Burraga and (*b*) Jimenbuen.

1). However, legume content alone did not indicate whether or not a location would be responsive to fertiliser addition. The SL position at the Burraga site had good legume content, but did not respond to fertiliser addition. This location, however, did have the highest level of exchangeable Al (22%). Evans *et al.* (1988) reported decline in subterranean clover herbage production when exchangeable Al exceeded 15% of total cation exchange capacity (CEC). High levels of Al impact directly on root development preventing cell division at the root tips resulting in stunting of the root system. This in turn affects the ability of the plant to harvest nutrients and moisture, thereby restricting growth. Further, low pH – high exchangeable Al soils reduce the survival of the rhizobia responsible for nodulation of subterranean clover (Munns 1968; Burnett *et al.* 1994). Without adequate nodulation, legumes fail to fix N for use by non-leguminous pasture plants and therefore there is limited capacity to respond to applied P. It is possible that high levels of Al affected legume growth at the SL position at the Burraga site and therefore restricted response to P application. Interestingly though, an additional fertiliser treatment consisting of lime (2.5 t/ha) applied in combination with 80 kg P/ha did not significantly increase overall total pasture or legume production compared with the nil P treatment. Another possibility is that under low pH – high exchangeable Al conditions at the SL position, rhizobium survival had declined over time, resulting in poor or ineffective nodulation of the subterranean clover and therefore limited N fixation, restricting N available to non-leguminous pasture components and limited ability to respond to applied P.

What are the implications of the findings of this study for fertiliser management in the future?

This study has found that pasture response to fertiliser application differed significantly across variable landscapes. In the paddocks used in this study, previous management had attempted to create greater uniformity in pasture composition through the introduction of annual legumes and at Jimenbuen, through the sowing of the perennial grass cocksfoot some 30 years earlier. Over the intervening period since the legume and/or perennial grass introductions, pasture composition had diverged resulting in distinctly different pasture communities based either on an aspect or within aspect basis. This was most apparent at the Jimenbuen site where cocksfoot was found only on the south facing aspect and

Table 1. Soil chemical, soil physical and botanical composition at north upper (NU), north lower (NL), south upper (SU) and south lower (SL) slope positions at the Burraga and Jimenbuen sites at the commencement of the study.

		NU	NL	SU	SL	l.s.d (P =0.05)
Burraga	Available $P_{Colwell}$	3.3[a]	7.5[ab]	11[bc]	14[c]	4.5
	Phosphorus buffering index	55	29	62	30	
	Al (% total CEC)	18[b]	10[a]	8[a]	22[c]	3.6
	Coarse particle fraction 0–80 cm (%)	62	22	29	7.0	
	Subterranean clover frequency (%)	17[a]	20[a]	67[b]	38[ab]	40
	Native perennial grass frequency (%)	39[a]	65[b]	65[b]	65[b]	14
Jimenbuen	Available $P_{Colwell}$	15[b]	15[b]	10[a]	10[a]	3.0
	Phosphorus buffering index	60	61	42	42	
	Al (% total CEC)	4.0[a]	10[b]	6.0[a]	8.0[b]	1.7
	Coarse particle fraction 0–80 cm (%)	55	41	48	69	
	Subterranean clover frequency (%)	10[a]	45[b]	100[c]	100[c]	20
	Native perennial grass frequency (%)	45[c]	40[bc]	26[a]	31[ab]	12

subterranean clover populations were higher on the south than the north facing aspects. Differences in microclimate, particularly moisture availability, or more specifically the consistency of moisture availability have probably been partially responsible for the differences observed in current plant communities across the sites. Overlaying this of course is the impact of grazing. In landscapes such as those used in this study, it is difficult to manage grazing for uniformity of pasture utilisation. Thus, areas of such paddocks may be under- or over-utilised which, over time results in plants tolerant of heavy grazing (those with low growing points and/or short life cycles) dominating in heavily grazed areas, while different communities are formed in less utilised areas. The results presented here show that predicting fertiliser responses is problematic, unless other factors are taken into account. How then do we attempt to best manage these landscapes?

In terms of managing fertiliser application, the results of this study have identified three key parameters which will assist in identifying areas capable of responding to P fertiliser addition:

1. **Assess any soil physical limitations in the landscape** – this will involve looking at soil depth and soil texture. Deep soils are capable of maintaining longer periods of pasture growth as they have the capacity to hold more moisture than shallow soils. Similarly, coarse textured soils will have less capacity to hold moisture than those with a finer texture. Assess whether the soil at different points in the landscape have any other physical limitations. For example, are there areas of landscape where the soil becomes waterlogged, thus restricting pasture growth.
2. **Assess the current composition of the pasture** – it is particularly important to be able to assess the legume content of the pasture. If legume content is lacking at specific areas in the landscape, then the capacity of that area to respond to application of P fertiliser will be limited. Certainly, botanical composition can be altered by introducing legumes into legume deficient pastures. However, assessment of pastures in their current state will give a good indication how position in the landscape has influenced the pasture composition. This may also give an indication of how successful introducing species such as legumes into the landscape may be.
3. **Assess possible soil chemical limitations** at locations in the landscape with favourable soil physical and botanical composition characteristics – often this is the first component considered in deciding whether or not to apply fertiliser to a pasture. However, unless soils have the ability to maintain good levels of moisture for prolonged periods and thus support a pasture with composition capable of responding to fertiliser application, then the worth of applying fertiliser needs to be questioned. It is also important to look further at soil tests than simply the level of available P. In many Tableland soils, Al toxicity is common. Where levels of exchangeable Al exceed 15% it is likely that subterranean clover production is being restricted either through root stunting and/or by reduced survival of rhizobia and therefore reduced nodulation and N fixation. There may be capacity to address surface acidity/Al toxicity through surface application of lime, however, be aware that the rate of amelioration using surface application is slow in comparison with incorporation. Additionally, consideration may need to be given to the reintroduction of rhizobia as it may have been reduced to negligible levels in the previously low pH – high Al conditions. Results from Western Australia have shown significant increases in old established subterranean clover pastures where rhizobia levels are deliberately increased through addition of inoculant.

If these three factors are considered, then it may be possible to implement a differential approach to fertiliser application – applying fertiliser only to areas with good moisture holding capacity and botanically favourable composition. Certainly, such an approach can significantly reduce expenditure on fertiliser – an important consideration for future farming practices, given the predicted increase in world fertiliser prices (van Kauwenbergh 2010). However, the effectiveness of such an approach in isolation will depend on the ability to utilise the additional pasture growth achieved. In highly variable landscapes, livestock are highly preferential in their grazing habits and the period of time they spend in specific areas of the landscape can be greatly influenced by weather conditions, as well as the species and breed of the grazing animal. Ultimately, the relative success, economic and/or environmental, of adopting a differential approach to input management, particularly with regard to fertiliser use, will depend on the ability to control grazing behaviour.

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