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POTASSIUM REQUIREMENT OF PASTURES GRAZED BY SHEEP AND BEEF CATTLE

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Abstract

Clover cover on grazed pastures (5 – 10%) on New Zealand sheep and beef farms is limited mainly by the lack of phosphorus (P) and sulphur (S), soil moisture deficits and competition for nutrients and light from low fertility-demanding grasses. Flat and easy slope trial sites, (three on sedimentary soils, two on pumice soils) with low soil QT K levels of 2 - 4 and initial 10 – 40 % clover cover were selected for K response trials over three years. Only at one site on a sedimentary soil in one year were any significant annual pasture dry matter (DM) production responses to K fertiliser measured. In the years of average to above average rainfall, especially on the two of the flat sites, clover cover in the spring increased with rate of K but this response was not reflected in total pasture DM production.

Of the three major nutrients required by clovers, P and S are the two most lacking in sheep and beef pastures and with soil K levels being generally in or above the economic optimal range, it is rational to optimise P and S inputs and rely on the supply of K from the soil mineral reserves. The soundness of this strategy was confirmed by the modelling of a typical hill sheep and beef farms with average soil QT K levels of 4-5 through the AgResearch PKS Lime econometric model. Over the following twenty years, a capital or annual maintenance application of K fertiliser resulted in small to large declines in Net Present Value compared with annual application of P and S only.

Examination of two large laboratory databases of soil QT K levels on sheep and beef farms comprised of 120,000 paddock samples over the last 7 – 10 years confirmed that about 90% of the results were in or above the economically optimal range of 4-5 for pasture production. Nor had there been any decline in soil QT K levels over that time. These results indicate that the recommendations made for K fertiliser on pastures grazed by sheep and beef cattle are generally sound and there is no foundation for any fears of a widespread shortage of K for optimum clover and pasture growth.

Introduction

Sheep and beef pastures are grown on soils derived from sedimentary (Brown, Pallic, Melanic, Ultic, Semi-arid soil orders)), volcanic ash (Allophanic, Granular) and pumice (Pumice). Most pastures are on soils of sedimentary origin where moderate weathering of clay minerals ensures an adequate supply of potassium (K) for clovers and pastures under sheep and beef grazing. Ash and pumice soils have parent materials that lack K-bearing clay minerals so are more likely to require some K fertiliser for optimal pasture growth. Because stocking rates are lower, especially on the predominant hill country, pasture K demand is also lower. Sheep also recycle K relatively efficiently although there is transfer of K in urine from steeper grazing areas to stock camp sites.

In a long-term trial on a sedimentary Brown soil on North Island hill country (average annual rainfall 1400 mm), after 13 years the farmlet receiving 250 kg superphosphate/ha/yr and stocked at 15 ewes/ha had an average soil Quick Test (QT) K level of 4.5 compared with the farmlet with no P and S applied and a stocking rate of 11 ewes/ha which had a soil QT K of 5.9 (Ledgard *et al*. 1997). A trial under sheep grazing on all aspects and slopes with cages showed a 0 and 21% response in pasture production to 100 kg K/ha/yr on the 0 and 250 kg superphosphate/ha/yr farmlets respectively. This response reflected a 5 and 22% increase in legume production (Ledgard *et al*. 1997). There was a downward trend in soil QT K levels over nine years where no K had been applied. The conclusion was that if pastures are adequately fertilised with P and S, the greater pasture production can use up the soil K reserves more quickly. Officer *et al.* (1997) found that on the relatively unweathered steep slopes, there were high mineral reserves of K that balanced the transfer of urine K.

AgResearch have compiled a database of all relevant K response trials which has been used to derive relationships between soil QT K and relative pasture production (Morton & Roberts 2017; Edmeades *et al*. 2010). To achieve near-maximum pasture production, soil QT K is required to be 6 – 8 on sedimentary soils and 7 – 10 on ash and pumice soils (Morton & Roberts 2017) with similar ranges established by Edmeades *et al*. (2010).

For sheep and beef farms, it is difficult from an economic aspect to justify the raising into and maintenance in the soil QT K ranges for near-maximum pasture production because of low product returns in relation to the cost of K fertiliser. The AgResearch PKS Lime econometric model which is based on response functions from the research trial database predicts the economically optimal soil QT K level to be in the range of 4 – 5 for most sheep and beef farms depending on animal production and gross margin per ha.

Recently there has been publicity regarding the occurrence of a widespread lack of K in pastures on sheep and beef farms. If this is proven to be so, the current strategy of mining soil K reserves while optimising P and S fertiliser inputs is not sustainable

This paper has been written to review recommendations for K on sheep and beef farms. We wish to answer three main questions:

1. What does some recent unpublished K research on sheep and beef pastures tell us regarding K fertiliser requirements?
2. What are the economic outcomes from optimising pasture production from P and S and maximising it from K compared with optimising all three nutrients using the AgResearch PKS Lime econometric model?
3. What do the large laboratory databases tell us about the proportion of paddocks with soil QT K levels in each range and are the levels declining over time from the current K fertiliser strategies?

Methodology

Research trials

In 2004, five of the original sixteen sites on the east coast of New Zealand that had been used to measure pasture production responses to P and nitrogen (N) for three years (Gillingham *et al*. 2007) were selected for low soil QT K levels (2 – 4). Three of the sites (Waipawa flat, Waipawa easy, Puketapu flat) were on Pallic soils and the other two (Wairoa flat and easy) were on Pumice soils. Flat sites were less than 15 degrees in slope and easy sites on slopes of about 20 degrees. Initial clover covers ranged from 10 – 40% for each site. The existing small mowing plots were used to apply treatments of 0, 15, 30, 50 and 80 kg K/ha/yr (2004/2005) and 0 and 50 kg N/ha/yr. Rates of K applied were doubled in 2005/2006 and 2006/2007. All fertiliser was applied in July. Each treatment was replicated four times in a factorial design.

Each month during the growth season of September to May, pasture production was measured using a Rising Plate Meter and clover cover assessed. Soil QT K levels were measured to 75 mm in each plot pre-fertiliser application in Year 1 and in the spring following fertiliser application in Years 2 and 3. Half of the clippings were returned to each plot after the site had been mown. Basal P and S fertiliser was applied annually. Pitau clover seed was oversown at each site before the start of the trial. Average annual rainfall was about 800 mm at Waipawa and Puketapu and 1300 mm at Wairoa.

Econometric modelling of K fertiliser strategies

A typical easy hill (average of 16 to 25 degrees slope) sheep and beef farm on a sedimentary soil with a stocking rate of 10 SU/ha and an average soil QT K level of 5, Olsen P 15 ug/ml and sulphate-S 6 ppm was modelled using the AgResearch PKS Lime econometric model. Gross margin per SU excluding fertiliser was $80 and the cost of K was $1.60/kg, P $3.20/kg and S $0.80/kg.

The programme models Net Present Value (NPV) for the next 20 years. Three scenarios were modelled:

- The current one of maintaining soil P (16 kg/ha/yr), K (0 kg/ha/yr) and S (25 kg/ha/yr) levels (Maintenance in Figure 1).
- Maximising pasture production by applying capital P (52 kg/ha in Year 1 followed by 18 kg /ha/yr), K (29 kg/ha in Year 1 followed by 0 kg/ha/yr) and S (30 kg /ha/yr) (Optimum in Figure 1).
- Optimising pasture production from applying P (16 kg/ha/yr) and S (20 kg/ha/yr) but maximising the pasture production from K by applying 35 kg K/ha/yr (User defined in Figure 1).

The case study farm was also modelled at a lower soil QT K level of 4 and stocking rate of 8 SU/ha to represent a steeper hill country farm with all other assumptions remaining the same.

Laboratory databases

An Analytical Research Laboratory (ARL) database of 23490 paddock soil QT K levels on sheep and beef farms in the North Island and another 61101 levels from sheep and beef farms in the South Island from 2005 to 2015 was examined. The soil QT K tests taken by Ballance Agri-Nutrients staff and analysed by Hill Laboratories from sheep and beef farms from 2009 to 2016 comprised another 44816 paddocks. The results were categorised into 4 categories – low (< 3), within economic optimum (4-5), above optimum (6-8) and high to excessive (> 9).

Results

Research trials

Soil QT K and annual pasture DM production

For each site and year, the soil QT K level for the control and the annual pasture DM production in response to K fertiliser is shown in Table 1. These results are for the non-N treatments.

Table 1: Annual pasture DM production response to fertiliser K (kg/ha) in relation to soil QT K level for control (2004/2005 K rates doubled in 2005/2006 and 2006/2007).

Site	Year	Soil QT K (control)	Pasture DM production (kg/ha/yr)					Significance of pasture DM production response
2004/2005 treatments			0	15	30	50	80	
Waipawa flat	2004/5	4	7400	6920	7440	8095	7635	NS
	2005/6	4	7295	7625	6810	7770	8140	NS
	2006/7	4	5750	6030	5900	6435	7130	NS
Waipawa easy	2004/5	5	3085	3130	2920	3105	3420	NS
	2005/6	6	3200	2925	3020	3470	3235	NS
	2006/7	5	2425	2345	2345	2725	2455	NS
Puketapu flat	2004/5	3	3930	4170	4260	4715	4485	NS
	2005/6	3	4600	4660	4825	5135	5085	NS
	2006/7	2	2930	3160	4065	4630	5085	**
Wairoa flat	2004/5	3	6980	6335	6360	6305	6200	NS
	2005/6	3	9140	9465	9130	9320	9690	NS
	2006/7	4	4445	4490	4670	4760	4695	NS
Wairoa easy	2004/5	2	3670	3615	2935	2600	3590	NS
	2005/6	3	4645	4690	4750	4775	5485	NS
	2006/7	2	1700	1945	1325	1420	2175	NS

The only significant response in annual pasture DM production to K ($P<0.01$) was at the Puketapu flat site in 2006/2007 when the soil QTK level for the control plots was 2. A soil QT K level of 2 for the control plots was also measured at the Wairoa easy site in 2004/2005 and 2006/2007 but there was no significant response ($P>0.05$) in pasture DM production.

Clover cover

A summary of the clover cover results in relation to annual rainfall are presented in Table 2

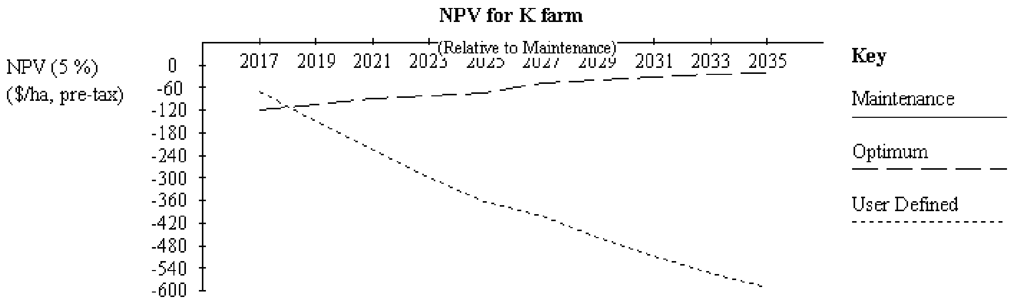
Table 2: The occurrence of significant (P<0.05) clover cover (%) responses to fertiliser K at each site in each year in relation to annual rainfall.

Site	Year	Annual rainfall	Month(s) of significant response to K in clover cover	Clover cover at lowest and highest rates of K	
				0 kg /ha/yr	80 or 160 kg /ha/yr
Waipawa flat	2004/5	Above average	September	65	90
			September	70	81
	2006/7	Average	November	63	76
Puketapu flat	2004/5	Above average	September	48	60
			October	68	83
	2005/6	Average	October	18	45
			November	13	43
			December	35	58
	2006/7	Average	September	20	55
			October	6	73
			January	24	58
Wairoa flat	2004/5	Average	February	58	72
	2005/6	Above average	September	16	62
			October	22	51
			November	28	66
	2006/7	Below average	September	7	36
			October	11	50
			November	19	52
Wairoa easy	2004/5	Average	December	13	38
	2005/6	Above average	October	35	70
			November	42	79
			December	38	80

Significant responses in clover cover to K tended to occur more on flat sites, in years of average to above average rainfall and during spring and early summer. The Waipawa easy site had higher soil QT K levels (5-6) than the other sites and there was no significant response in clover cover to K.

Econometric modelling of K fertiliser strategies

As shown in Figure 1, the most economic strategy in terms of Net Present Value (NPV) was to maintain soil P and S levels but to apply no K fertiliser (Maintenance scenario). When this strategy for P, S and K was compared with optimising P and S but applying 35 kg K/ha/yr (User defined scenario), the NPV for the latter strategy quickly declined from Year 1 losing about $70/ha in Year 1 to $600/ha in Year 20 compared with the maintenance scenario. The Optimum scenario of applying capital P and K in Year 1 resulted in a decrease in NPV of about $120/ha dropping to a decrease of about $60/ha in Year 20, compared with the maintenance scenario. At the steeper hill country scenario with a soil QT K level of 4 and a lower stocking rate of 8 SU/ha, there was still no economic justification for the application of K fertiliser (results not shown).



NPV (5 %)	Block	Scenario	2017	2019	2021	2023	2025	2027	2029	2031	2033	2035
($/ha, pre-tax)	K farm	Maintenance	-	-	-	-	-	-	-	-	-	-
(Relative to Maintenance)	K farm	Optimum	-120	-103	-91	-81	-73	-49	-40	-32	-26	-20
	K farm	User Defined	-71	-150	-227	-299	-364	-401	-458	-508	-553	-594

Figure 1: Long term NPV ($/ha) for different fertiliser strategies on a typical sheep and beef farm.

Laboratory databases

For the ARL database, the proportion of paddock soil QT K levels in each range for each year from all soil groups are shown in Table 3.

Table 3: Percentage of paddock soil QT K levels in each range for each year from 2009 to 2015.

Year	Soil QT K			
	3 and less	4 - 5	6 - 8	9 and greater
2005	3	30	23	44
2006	3	30	24	43
2007	1	23	22	54
2008	2	28	23	47
2009	1	28	23	48
2010	1	26	24	49
2011	1	25	24	50
2012	3	28	23	46
2013	3	29	26	42
2014	2	28	21	49
2015	2	25	22	51

This data shows that there is no indication of any change in soil QT K level on sheep and beef farms over the last ten years. Some 60 – 70% of paddocks were above the economically optimal range with most of the remainder within the optimal range.

These results are similar to those from the Hills Laboratories database where 6% of the paddocks were in the low range (less than 3), 33% in the economically optimal range (4 – 5), 25% in the above optimal range (6 – 8) and 36% in the high to excessive range (9 and above). There was also little change in paddock soil QT K levels over time. This is shown for the sedimentary soils, present in the majority of the paddocks, in Figure 2. The results for the other soil groups showed a similar trend (data not presented).

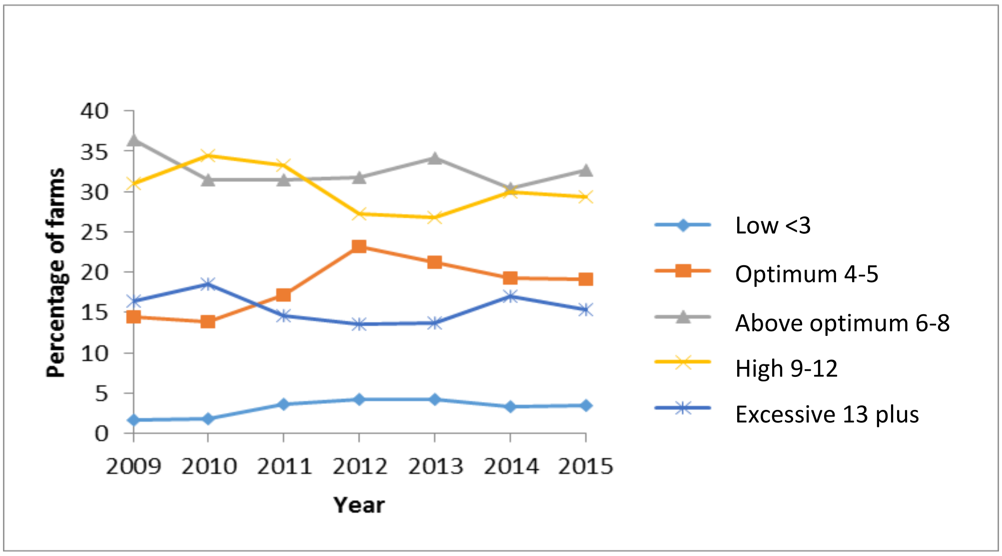


Figure 2: Soil QT K levels for sheep and beef farms on sedimentary soils.

Discussion

The trial results from the five K response sites indicate that even at soil QTK levels of 3 and less, it is not always possible to measure a significant response in pasture production to K fertiliser. Because grasses are more efficient at extracting K from the soil than clovers and low-fertility demanding grasses such as browntop may have a low K demand anyway, the opportunity for clover to grow would appear to be necessary for a pasture to respond to K. These mown trial sites had an artificially high clover cover compared to what is normally present in pastures grazed by sheep and beef cattle. For three years before the application of the K treatments, the pasture swards had been regularly mown which favoured the growth of the more prostate clovers by allowing less shading by grasses. The grazed pasture outside the fenced trial sites had a much lower clover cover than the no K control plots in the trial. Grazed pastures, especially in hill country, have an inherently low clover cover because of preferential grazing by sheep, moisture stress and competition from grasses. Lambert *et al.* (1986) failed to maintain a significant clover content in sheep-grazed pasture at Ballantrae Research Station despite the application of 375 kg superphosphate/ha/yr and being in the early stage of pasture development where grasses lack N and are not as competitive.

However it might have been expected that the response in clover cover to K shown in Table 2 at all the sites except Waipawa easy sites would have been reflected in more significant responses in total pasture production to K than occurred in one year at the Puketapu flat site. This lack of response in total pasture production to K may have been caused by the substitution of clover DM for grass DM. Despite the lack of response in total pasture production to K in this series of trials, the rational approach is to consider the main body of research rather than focus on individual trial results. This database shows that developed pastures generally require K fertiliser at soil QT K levels of 3 and below. The reported trial series does however demonstrate the importance of other factors apart from soil QT K such as background clover cover, rainfall and slope that relate to the size of the pasture production response to K. On the drier east coast of New Zealand, the matching requirements of adequate rainfall and temperature that boosts spring and early summer clover growth, especially in hill country, now only tend to occur on average every 4 – 5 years (eg. 2011 and 2016). Therefore there are limited opportunities for responses in clover growth to K fertiliser in grazed pasture. Where adequate rainfall is more consistent closer to the central mountain ranges and in western areas, there is more opportunity for clover and hence pasture to respond to K fertiliser. Conducting the trials for longer may have increased the grass content of the sward as clover N supply increased and resulted in a greater total pasture DM response to K.

Pumice and ash soils lack the soil K reserves of sedimentary soils such as those in the Recent and Pallic soil orders and may require more fertiliser K. The Hills Laboratory database showed similar proportions of paddocks in the soil QT K ranges for pumice and ash soils to sedimentary soils indicating that this greater requirement is being recognised.

The response functions for K in the AgResearch PKS Lime Model are based on the database of research trials described by Edmeades (1995). They are represented by the curve showing the relationships between soil QT K and relative pasture production in the Industry Booklet "Fertiliser Use on New Zealand Sheep and Beef Farms" (Morton & Roberts 2017). These relationships show that the soil test K levels which sustain near maximum pasture production are 6 (range 5 – 8) for sedimentary soils (mainly Brown and Pallic soil orders) and 7 (range 7 – 10) for Ash (Allophanic) and Pumice soils. Edmeades *et al*. (2010) published the response functions for various soil groups based on largely the same database. For the same level of pasture production (97% of maximum) they derived critical soil QT K levels of 6 for sedimentary (range 5 – 10) and ash soils (range 4 to > 10) and 7 for Pumice soils (range 5 – 10). Therefore the response functions from the two sources that were mainly derived from the same body of research are largely similar. Edmeades *et al*. (2010) also described a probability approach to K requirements where there was still a 10% probability of gaining a pasture production response at a soil QT K levels of about 10. The limitation of this probability approach is that it is qualitative in nature and does not define the size of the response. Consideration of the K response functions in the same paper would indicate that the response is likely to be very small (<5%). In addition a probability level of 10% is very low. Experimental protocol requires a probability of greater than 90 - 95% before a response can be deemed to be real.

Most fertiliser budgets on sheep and beef farms are limited by the variation in profitability between years so farmers tend to optimise the return from fertiliser by applying P and S and utilising soil reserves of K. This strategy for K is validated by the output from the AgResearch PKS Lime model. For typical farm production, a soil QTK level of 4-5 which on average and depending upon the level of production will sustain near maximum pasture production on the sedimentary soils on which the greatest number of sheep and beef cattle are farmed. The high level of relative pasture production (>90%) at soil QT K levels of 4 -5 makes the application of K fertiliser uneconomic where these levels exist. Annual application of K fertiliser at this level of soil K to maximise and not optimise pasture production resulted in a rapid and large reduction in NPV. The cost of a kilogram of K fertiliser may be about half that of a kilogram of P but the economic returns from both nutrients also need to be considered as occurs in the AgResearch PKS Lime model.

The large variability in the relationship between soil QT K and pasture production (Edmeades *et al*. 2010) can mean that on some sites, near-maximum pasture production will be sustained at soil QT K levels lower (as evidenced by the trial series reported here) or greater (eg. Ledgard *et al*. 1993) than the average level of 3 for sedimentary, ash and pumice soils where average relative pasture production is less than 90% (Morton & Roberts 2017). In other words, the response functions for each trial site are different to the average response function in the AgResearch PKS Lime model. In the situations where pasture production responses occur at soil QT K levels greater than 3, other observational and analytical methods need to be employed in the field such as assessment of clover cover and vigour and analysis of clover K.

It is the paddocks on the farms that lack K that are probably more frequently encountered by independent advisors when they are called in to solve a problem. Independent advisors are also involved with a much smaller number of farms than those represented in the large laboratory databases. However, in our opinion it is risky to extrapolate the lower soil QT K levels from these paddocks and postulate a widespread lack of K for pasture growth. On some of these paddocks that lack K, a fertiliser K recommendation may have been made but the farmer chose not to apply K for reasons of finance or concern over animal health. The large laboratory databases clearly indicate that the current strategy of utilising mineral K reserves on sedimentary soils is having no measurable effect on soil QT K levels over time. The soundness of the current K fertiliser strategy on sheep and beef pastures is also supported by the large proportion within or above the economically optimal range.

Conclusions

1. K response trials carried out on sheep and beef pastures with low soil K levels (2 – 4) at five sites for three years showed a significant total pasture production response only at one site in one year. Consistent responses to K in clover cover during spring and early summers with average to above average rainfall at four of the sites indicated that grass growth may have been substituted for by clover growth.
2. Econometric modelling showed that the most profitable strategy for sheep and beef pastures on the predominant sedimentary soils is to optimise P and S applications and utilise the mineral K reserves in the soil.
3. Two large databases of paddock soil QT K levels from sheep and beef pastures showed there was little change in the average values over the last seven to ten years and that nearly all the levels were within or above the economically optimal range.

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