Is soil fertility a factor limiting pasture production and persistence in New Zealand?

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Highlights

Clover-based pastures are an important foundation on which New Zealand's $38b pastoral sector is based. However, clover has a higher requirement for all nutrients than the associated companion grasses and does not persist when the soil fertility is less than optimal. This paper summarises data on the nutrient status of pastoral soils in New Zealand collected in the last 20 odd years. It is found that most New Zealand pastoral soils are sub-optimal in respect to optimal clover growth. It is suggested that this is a factor limiting the production and persistence of clover-based pastures in New Zealand. The data suggest that many New Zealand pastures are operating at about 60%-80% of potential pasture production.

Keywords: clover, pasture persistence, pasture production, soil fertility, soil testing

Background

Clover-based pastures are an important foundation on which New Zealand's pastoral sector depends – it is the largest industry in New Zealand earning $38 b annually. The nitrogen (N) dynamics of this system are well understood. Clover, typically white clover (*Trifolium repens*), is a key component – not only is it a better food-source for ruminants but importantly it is a forage legume which 'fixes' atmospheric nitrogen (N) (Caradus et al. 1996, Clark and Harris 1996), which is ultimately added to the soil, either via animal excreta, or the mineralization of clover plant residues. In the absence of fertiliser N, these clover N inputs are sufficient to drive the production of the companion grasses. Pasture eaten is an important measure of the productivity of such systems and the national average over the period 2000-2020 is 10.5 to 11.5 tonnes DM/ha/year (Chapman et al. 2024)

White clover requires 16 nutrients to complete its life-cycle and much research has been completed to define the amounts of each nutrient required to optimise total pasture production (Morton and Roberts 2024; Roberts and Morton 2023). However, clover has a higher requirement for all these nutrients relative the companion grasses. (Caradus et al. 1995). When capital fertiliser is required during pasture development, clover is the initial dominant species and this can be the case for several years until sufficient N, from the clover, has accumulated in the soil to optimise the production of the N dependant companion grasses (Edmeades et al. 2010). The reverse applies: if the soil nutrient levels are not optimal for clover growth, it is the first species to disappear from the pasture, and, as clover-N inputs decline, so too does the production of high producing grasses.

Farmers, confronted with declining pasture production and/or poor pasture persistence, are frequently advised to either re-sow their pastures with the latest ryegrass/white clover cultivars and/or apply fertiliser N. Neither approach provides a sustainable long-term, cost-effective solution to the problem. The marginal cost of clover-based pasture dry matter (DM) (4-5 cents/kg DM) is less than the marginal cost of ryegrass pasture DM dependent on fertiliser N (10-12 cents/kg DM). Furthermore resowing a clover-based pasture is ineffective if the soil fertility is not optimal for clover.

Historically considerable research has been directed toward improving the major forage species, specifically white clover and ryegrass (*Lolium perenne*) and much progress was made (Caradus et al. 2024). However, recent evidence indicates that while there have been some improvements in forage plant breeding over the past 20 years, these improvements have not always been captured 'on farm' (Caradus et al. 2024, Chapman et al. 2024). Indeed, Chapman et al. (2024) suggested that what progress has been made in terms of improving pasture productivity on-farm in the last 20 years can be attributed to the increasing use of fertiliser nitrogen (N) and an increase in stocking rate. We hypothesise that suboptimal soil fertility is a factor restraining the productivity and persistence of clover-based pastures in New Zealand. The data summarised in this paper indicates that this problem is widespread in both the sheep & beef and dairy sectors.

The objective of this paper is to review all the available information on the soil fertility status of New Zealand pastoral topsoil's (0-75mm) since 1988, and compare this information with the critical nutrient levels required to achieve optimal production in clover-based pastures. This review will focus exclusively on

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the main macronutrients phosphorus (P), potassium (K) and sulphur (S).

Results

There is no routine systematic, nationwide monitoring of the soil fertility (0-75mm) of NZ's pastoral soils. Most Regional Councils undertake formal routine measurements to monitor soil quality in their regions, as part of the State of Environment reporting but these results are of limited value for the purposes of this review, given that the prescribed soil depth 0-100 mm is used and the soil fertility data collected and reported is limited to Olsen P. Also, the fertiliser industry (Fertiliser Association of New Zealand) have summarised results (0-75mm) collected from their farmer clients for the period 2012 to 2022, but reporting is again limited to Olsen P data.

The nutrient status of soil samples collected from sheep & beef, and dairy farms, in the North Island, was first examined using the results from a commercial soil testing (MAF Soil Fertility Service (SFS)) laboratory (Ledgard et al. 1991). This database consisted of soil samples (n = 4700) collected over the period 1988 to 1991. These results were compared to the optimum soil test levels required to achieve near maximum pasture production (Edmeades et al. 2005; 2006; 2010). They found that across all 3 soil types examined (Pumice, Ash and Recent) about 40% were below the optimal Olsen P levels on the sheep & beef farms and 65% on the dairy farms. In addition, about 50% were below optimal for sulphur (S) and potassium (K) (Table 1). Based on this evidence they predicted that increases in pasture production of 10-30% were likely on these soils if the correct nutrients were applied.

Wheeler and Roberts (1997) extended this database to include 65,000 commercial samples, including results from both the North and South Islands. Their results are summarised in Table 2. For the samples from the North Island, averaged across all the soil groups examined, about 84% of the sheep & beef farms had Olsen P levels below optimal together with 60% of the dairy farms. The comparable figures for the South Island were 80% (sheep & beef) and 60% (dairy). Sulphate S levels were below the optimal in about 50% of the North Island samples and about 80% in the South Island. For soil K (Quick test K, QTK) the results were below optimal in about 47% of the samples (North Island) and between 36% - 60% in the South Island (Table 2).

Wheeler et al. (2004) added further to this database, which now included 246,000 samples collected over 14 years (1988 through to 2001). Their data (Table 3) indicates that across all 4 soil groups examined on sheep and beef farms, the percentage of samples below optimal Olsen P was about 82% for the period 1988 to 1996 and 72% from 1997 to 2001. For the samples from dairy farms 55% were below the optimal Olsen P for the period 1988-96 and 27% were suboptimal for the period 1997-2001. There were no obvious trends in the data over the period 1988 to 2001 except for the Olsen P levels which increased on both dairy farms and sheep and beef initially (1988 to 1995) but then plateaued after 1995.

McBride and Edmeades (2020), applied a more robust approach. In the course of providing fertiliser advice to farmers in the South Island between 2010 and 2020, agKnowledge Ltd assessed the soil fertility using 3 criteria: soil tests, clover-only tests, and Pasture Visual Assessments (PVA) (McBride and Edmeades 2020, Edmeades 2021), assessed when the clover was growing in autumn and spring. For the purpose of developing fertiliser plans, farms were divided into blocks based on land use, topography and soil nutrient status. In this dataset, there were 533 separate blocks which were distributed as follows: 146 milking platforms, 73 effluent blocks and 308 dry-stock blocks. The dry-stock blocks were further divided based on stocking rate into 'low' (n=104), 'typical' (n=129) and 'high' (n=75). These data were collected during the initial farm visit and before any remedial action was taken. The distribution of the farms was as follows: Southland (38%), Canterbury (37%), Otago (21%) and Westland/Tasman (4%). The full set of results is available elsewhere (McBride and Edmeades 2020).

The results indicate that these farms were operating at about 60% to 80% of their potential in terms of pasture production (McBride and Edmeades 2020) and that the clover content of the pastures was about 50% of what is accepted as desirable (30%-40%) (Clark and Harris 1996).

Clover-only samples were analysed from each block.

Table 1 Proportion of North Island soil samples collected from Pumice, Ash and Recent soil groups deficient in phosphorous (P), potassium (K) or sulphur (S).

Proportion (%) of North Island soil samples (0-75 mm) below optimal[1].			
	Olsen P	QTK	Sulphate S
Sheep & Beef	40 (< 17)[1]	26 (<5)	42 (< 6)
Dairy	65 (< 26)	67 (< 8)	26 (< 8)

[1]The figures in parenthesis are the criteria used in this study to define deficiency.

Table 2 Proportion of soil samples deficient in either phosphorus (P), potassium (K) and sulphur (S) in sheep & beef and dairy farms.

Proportion of soil samples deficient[1] (%) in either in phosphorus (P), potassium (K) or sulphur (S).				
		P	K	S
North Island	Sheep & Beef	86	46	43
	Dairy	60	46	52
South Island	Sheep & Beef	80	36	85
	Dairy	60	60	75

1) for the criteria applied in this study see Wheeler and Roberts (1997).

Table 3 Proportion of soil samples deficient in phosphorus (Olsen P) on sheep & beef and dairy farms for the period 1988-1996 and 1997-2001. Derived from Wheeler et al (2004).

Proportion (%) of soil samples deficient[1] in Olsen P for the period 1998-1996 and 1997-2001		
	1988-1996	1997-2001
Sheep & Beef	82	72
Dairy	55	27

[1]See Morton and Roberts (2023) and Roberts and Morton (2022) for the criteria applied in this study.

Table 4 Pasture Visual Assessments of pastures on dairy (208) and drystock (272) farms in the South Island over the period 2010 to 2020.

Pasture Visual Assessments[1]		
	Dairy (n=208)	Drystock (n=272)
Vigour (1-10)	5.5	4.5
Clover (%)	17	15

[1]See McBride and Edmeades (2020) and Edmeades (2021)

Table 5 Proportion (%) of clover-only samples deficient in phosphorus (P), potassium (K) and sulphur (S) on dairy and drystock farms in the South Island over the period 2010 to 2020.

Clover-only samples (% deficient)[1] (summarised from McBride and Edmeades 2020)		
	Dairy (n=128)	Drystock (n=313)
Phosphorus (P)	10	26
Potassium (K)	67	53
Sulphur (S)	10	5

[1]See Morton and Roberts (2023) and Roberts and Morton (2024) for the criteria applied in this study.

Table 6 Proportion (%) of soil samples deficient in phosphorous (P), potassium (K) and suphur (S) on dairy and drystock famers in the South Island over the period 2010 to 2020. (Derived from McBride and Edmeades 2020).

Soil test (% deficient)[1]		
	Dairy (n=219)	Drystock (n=308)
Olsen P	82	42
Soil K	65	57
Soil S	67	78

[1]See Morton and Roberts (2023) and Roberts and Morton (2024) for the criteria applied in this study.

The results from the dairy farms, (Table 5) show that overall, 67% of the blocks sampled were potassium (K) deficient. The results were similar for effluent blocks and the milking platforms. Furthermore, similar results (Table 5) for K (53%) were found on the dry-stock farms, which were also often phosphorus (P) (26%) and sulphur (S) (35%) deficient**.**

The soil test results from the dairy farms are given in (Table 6) and show that P is very often below the economic optimal range (82%), and that K (65%) and S (sulphate S, 61%, organic S 67%) were below the respective biological optimal ranges. For the dry-stock farms S (sulphate 62%, organic S 78%) and K (57%) were most often deficient followed by P (42%).

Discussion

The concerns expressed by Wheeler et al. (2004) about the interpretation of the result from these types of data-sets must be heeded - it applies to all the data sets used in this paper. They are not surveys based on statistically designed protocols and procedures and at best they represent 'snapshots' of the soil fertility NZ pastoral soils at given times. Importantly, note that the criteria used to define the deficient/optimal levels for the various tests are similar but not necessarily the same. For this reason a qualitative interpretation only is possible.

At this general level the combined evidence from all the data sets examined indicates that many pastoral soils in New Zealand are suboptimal for growing clover-based pastures and it appears that this has been the case for some time. This conclusion is at odds with data from the Fertiliser Association of New Zealand (2024) who suggest, based on soil test results from their clients, that Olsen P levels are typically in the optimal range associated with the major soil groups. Data for the other nutrients K and S are not presented. The likely reason for this discrepancy in that fertiliser industry use a soil sampling protocol aimed at measuring the average soil fertility of the sampling area (Roberts *pers. com*.) rather than, more correctly for the purposes of offering fertiliser advice, the average of the areas of poor pasture growth. Morton et al. (2017) suggested, based on 5 K trials on the East Coast of the North Island, that the optimal soil K level was lower on these soils. It is noted that this subset of trials were included in the large data-base from which the optimal K range of 7-10 was derived (Edmeades et al. 2010).

It is suggested that this is a possible reason for the lack of progress towards improving pasture productivity and persistence on-farm in New Zealand (Caradus et al. 2024, Chapman et al. 2024).Applying these results to the relevant soil fertility pasture production functions (Edmeades et al. 2005, 2006, 2010), it is predicted that on many farms it should be possible to increase total pasture production by 20% to 40%, by applying current technology in soil fertility and pasture nutrition. This is similar to that suggested by Ledgard et al. (1991).

Soil test results are inherently variable even when the proper sampling protocols are applied (Edmeades et al 1988). To overcome this problem soil tests should be 'ground proofed'- are the results consistent with other independent criteria? This can be done by comparing the soil test results with the nutrient content of clover-only samples, assuming once again that they have been collected using the correct protocol. As noted earlier, clover has a higher requirement for all nutrients relative to grasses and for this reason is more sensitive to nutrient deficiencies. An alternative is to assess the pastures visually. For this purpose agKnowledge (2004) Ltd has developed a Pasture Visual Assessment (PVA) system, which can be used to assess the quality and vigour of clover-based pastures reflecting the underlying soil fertility (McBride and Edmeades 2020; Edmeades 2021). For these reasons the results reported by McBride and Edmeades (2020) are of particular relevance to the hypothesis being examined in this paper.

Given that the soil fertility of NZ pastoral soils is a mature science and given the importance of the pastoral sector to the nation's economy, the question arises: how has this situation been overlooked. Several factors could have contributing to this problem. First, the increased use of N fertiliser, in both the sheep & beef and dairy sectors, and supplements in the dairy sector, has shifted the focus away from the importance of the clover-based pasture as the sole factor driving animal production. Secondly, the pastoral sector's attention has been averted over the last 2-3 decades by the more immediate need to address the environmental issues, relating to fertiliser use, confronting the sector. Thirdly, in the last 2 decades major reviews have been published on the nutrient requirements for phosphorus (P), potassium (K) and sulphur (S) of clover-based pastures in New Zealand. This has resulted in adjustments to the P, K and S pasture production functions and some changes to the critical levels for soil tests and modifications to the interpretation of some soil tests such as Organic S and, in particular, the Reserve K (Edmeades et al. 2005; 2006; 2010) .

Practical Implications

These results have particular relevance to all pastoral farmers. It is important that the soil fertility of their pastoral soils is regularly assessed and interpreted using the most recent science. The PVA booklet with its accompanying photographs may be useful in ground-proofing the soil test results. At least these photographs will provide a picture of what a healthy clover-based pasture should look like.

To assist their clients, Farm Consultants may need to be reminded of the importance of clover-based pastures, not just to the individual farmer, but also the pastoral sector generally, and upskill themselves regarding our current understanding of the nutrient requirements of clover-based pastures.

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