Building a solid foundation for pasture production in Northland: P, K, S and lime requirements

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Abstract

The generally strongly weathered, leached soils of Northland consist of four major soil groups. The yellow-brown earths and podzols and yellow brown sands are formed from sedimentary rocks, while brown granular clays and red and brown loams are formed from volcanic rocks. In terms of the relationship between pasture production and fertiliser nutrient requirements, for both sedimentary and volcanic soils, the production functions are shown to be of the "diminishing returns" type, and the point at which near-maximum production (97%) occurs is defined as the "biological optimum" soil test level. Biological optimum test values for sedimentary and volcanic soils are: Olsen P 20 and 22; quicktest K 6 and 7; sulphate-S 10; organic-S 15; and pH 5.9. Once biological optimum soil test levels have been attained then maintenance fertiliser nutrient rates are appropriate. In order to move up the pasture production curve an average of 7 and 11 kg P/ha above maintenance will increase Olsen P by 1 unit for Northland sedimentary and volcanic soils respectively. Similarly, on average 60 kg K/ha will raise quicktest K by 1 unit on volcanic soils, but capital requirements for K on sedimentary soils in Northland are not known. An average of 35 and 25 kg S/ha will correct S deficiencies on sedimentary and volcanic soils.

Keywords: biological optimum, lime, Northland, nutrient requirements, phosphorus, potassium, sedimentary soils, sulphur, volcanic soils

Introduction

Soils are formed by a number of factors, including parent material, climate, time, topography, soil-living organisms (Jenny 1941) and the modifying influence of human activity. Soil processes (e.g., leaching, podzolisation, gleying, humification and biological disturbance) acting in conjunction with the soil-forming factors result in the soil mantle, which is one of the fundamental resources available to farmers.

Although soils are the growing media for pasture, in their natural state they may be deficient in one or more of the essential elements required for maximum pasture productivity. If the farmer's objective is to produce as much pasture as possible then these deficiencies will need to be corrected. The assessment of soil fertility, on farm, is generally most often made using a combination of soil testing and past fertiliser history and then deciding on nutrient requirements accordingly. Soil tests are estimates of a proportion of the plant-available nutrients in the soil, and as such are useful only if the tests can be interpreted in the light of some meaningful parameter on the farm, i.e., soil tests must be "calibrated".

Recently over 3000 data sets derived from archival and recent soil fertility trials, conducted by MAF and AgResearch science staff, have been collated into an electronic database, and analysis of this information has enabled the relationships (production functions) between relative pasture production and soil tests for phosphorus (P), potassium (K) and sulphur (S) to be defined. Previously, only limited data relating soil test (primarily Olsen P) and pasture production have been published (Grigg 1977; Saunders et *al.* 1987).

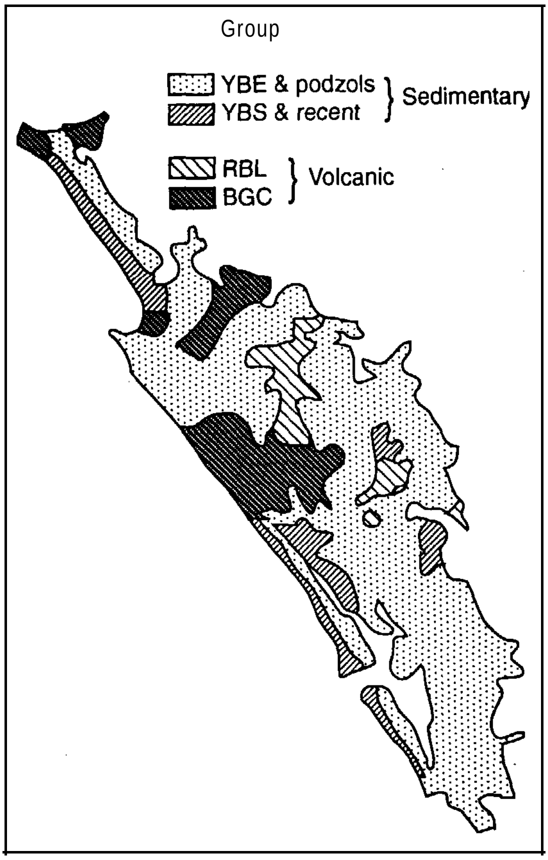
The purpose of this paper is to present the production functions relating relative pasture production to soil test P, K, S and pH for Northland soils and discuss technologies for the assessment of current soil fertility status and determination of nutrient requirements.

Soils of Northland

Northland soils tend to be strongly weathered owing to the generally warm, moist climate. Some soils have been highly leached, the degree of leaching depending on the original vegetation present. In general, Northland soils are of low fertility in their natural, undeveloped state.

Four major soil groups make up the soil mantle in Northland (Figure 1). The yellow-brown earths (YBE) and podzols cover the largest area of around 560 000 ha followed by the brown granular clays (BGC) and loams at around 240 000 ha. Smaller areas of red and brown loams (RBL) at 77 000 ha and yellow-brown sands (YBS) at 40 000 ha make up the remaining area. The YBE and YBS soils are derived from sedimentary rocks such as greywacke, mudstone and sandstone, whereas the BGC and RBL soils are derived from volcanic rocks such as basalt.

Figure 1 Generalised soil groups in Northland.



There are major physical differences between the above soils which influence pasture productivity. For example, the volcanic RBL soils have excellent soil structure and so are free-draining, whereas the sedimentary YBE soils are generally heavy clays and hence poorly draining and can be easily damaged by treading or machinery when wet. The light YBS soils, in contrast, are drought-prone.

P, K, S and lime requirements for Northland soils

The soils of Northland fall into two categories, namely volcanic (BGC, RBL) and sedimentary (YBE, YBS), in terms of the relationship between soil fertility and pasture growth. Relevant trials conducted on volcanic and sedimentary soils from throughout the North Island and including those from Northland have been grouped together to determine the relationships between relative pasture production and soil tests (production functions).

This approach is valid because (a) the soil chemistry with respect to P, K and S within the groupings will be similar; (b) data from individual trials are often variable and combining data from a number of sites or similar soils reduces this variability (Sinclair et *al.* 1994) and enables meaningful **average** relationships to be developed; (c) these relationships have practical meaning at the farm level, given the precision required for making fertiliser recommendations.

The production functions have been developed using spline functions (Upsdell 1985) and the 95% confidence intervals for the average relationships are also shown. *In* general, the production functions are curvilinear. The "biological optimum" soil test level has been defined as that at which 97% of relative pasture production is achieved. The 97% has been arbitrarily chosen because that level is close to near-maximum pasture production and, by definition, diminishing returns curves of the Mitscherlich type will reach 100% only at infinity. Once the biological optimum soil test has been ascertained, a target range, incorporating the biological optimum, is specified because quoting a single soil test value attributes too much precision to soil testing. The target soil test range implies a high probability of sustaining near-maximum pasture production.

Phosphorus

The predominant soil test used for assessing the P status of New Zealand soils is the Olsen test (Olsen et *al.* 1954). The biological optimum Olsen P test for volcanic soils is 22 (Figure 2) and for sedimentary soils is 20 (Figure 3) while the target ranges are 20-30 and 20-25 for volcanic and sedimentary soils respectively. In 1989/90, 55% of dairy farm and 82% of sheep-beef farm samples tested by the Soil Fertility Service were less than or equal to an Olsen P of 20 (Table 1), i.e., less than the biological optimum for sedimentary soils. However, by 1994/95 this 'had decreased to 2 1% for dairy farms and 56% for sheep-beef farms (Table 1). The number of dairy farms with Olsen P of 26 or more has doubled over the past 5 years (Table 1), presumably as a reflection of the increased profitability of dairying and capital rates of P fertiliser being applied. Although profitability of sheep-beef farming is generally not as high as for dairying, samples with Olsen P levels of more than 26 have increased 20%. It is acknowledged that the comparison of soil test values in 1989/90 and 1994/95 is flawed by the fact that the populations of farm samples in the two different time periods will be different. Nevertheless, the comparison does give a reasonable indication of the trend in soil tests over time.

Figure 2 The relationship between relative pasture production and Olsen P for volcanic soils.

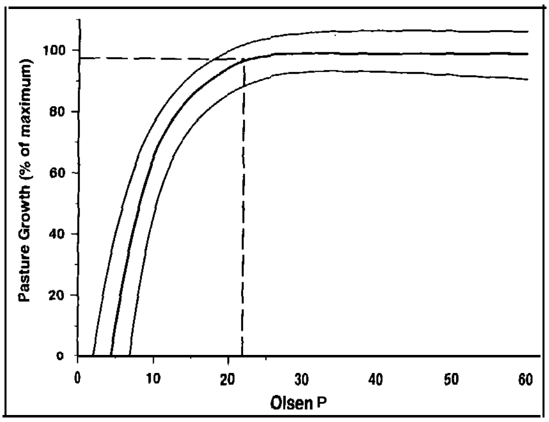
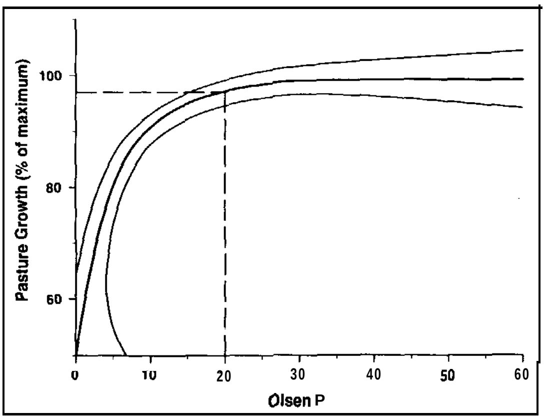


Figure 3 The relationship between relative pasture production and Olsen P for sedimentary soils.



If the Olsen P status of volcanic and sedimentary soils are low, then large capital inputs of P fertiliser are required for a rapid increase to occur, and in practice it is much more effective to apply a high rate over 1 or 2 years than to apply the same amount of P over several years. Capital applications of P to raise Olsen test by I unit, above that required to maintain existing soil test levels, average 1 I kg P/ha (range 7-18) for volcanic soils and 5 kg P/ha (range 4-7) for sedimentary soils. However, in a recent series of trials conducted specifically in Northland, an average input of 7 kg P/ ha has been shown to be required to raise Olsen P by l unit on sedimentary soils (M.B. O'Connor pers. comm.). In practice, this means that raising Olser, P from I5 to 25 (i.e., 10 units) will require 1220 and 780 kg superphosphateiha (or equivalent) for volcanic and sedimentary soils respectively.

Table l The P fertility status of Northland soils in 1989/90 and 1994/95

Olsen P	1989/90		1994/95	
	Dairy	Sheep-beef	Dairy	Sheep-beef
20	55%	62%	21%	56%
≤ 21-25	15%	9%	15%	16%
26+	30%	9%	64%	29%

Potassium

The quicktest potassium (QTK) test (Cornforth 1980) is most commonly used to assess K fertility of soils. The relationships between pasture production and QTK for volcanic and sedimentary soils are similar (Figures 4 and 5) with biological optimums of 7 and 6 respectively. The target ranges to sustain near-maximum production are 7-10 for volcanic and 6-8 for sedimentary soils. In 1989/90, the quicktest K status was similar for both dairy and sheep-beef farms, with 34 and 36% respectively, of samples being greater than QTK 9 while the comparative figure in 1994/95 had dropped slightly to 28% and 26% respectively (Table 2). Provided that soil K tests are mostly between 6 and 9, the decrease in high soil test K levels is a positive move in helping reduce the impact that high K content of forage exerts on Mg adsorption by grazing animals (Roberts 1994).

Research results indicate that capital applications of K to raise QTK by 1 unit averages 60 kg K/ha (range 45-80) for volcanic soils, or the equivalent of 120 kg/ha muriate of potash (KCl). There are no data available for assessing capital requirements for sedimentary soils in Northland and, in fact, on some soils such as sands and podzols it is difficult to raise the K levels because of leaching. Some sedimentary

Figure 4 The relationship between relative pasture production and soil test K for volcanic soils.

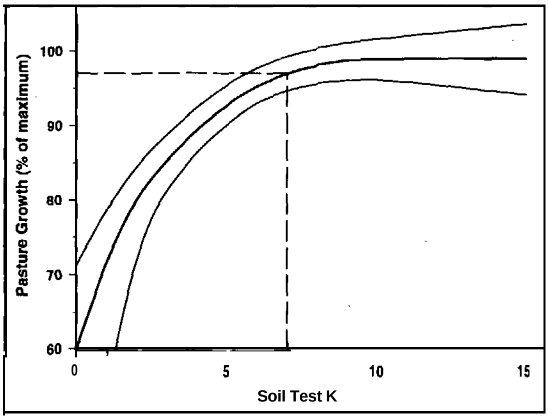


Figure 5 The relationship between relative pasture production and soil test K for sedimentary soils.

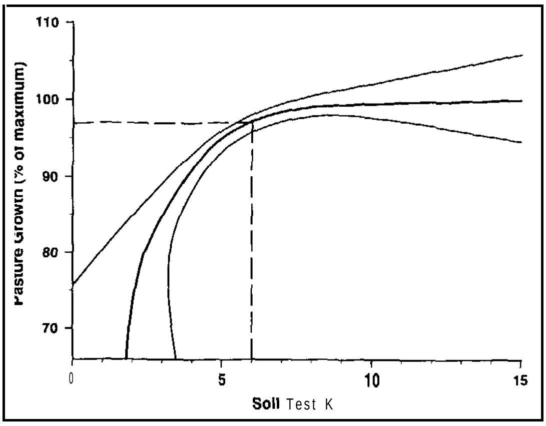


Figure 6 The relationship between relative pasture production and soil sulphate for all soils.

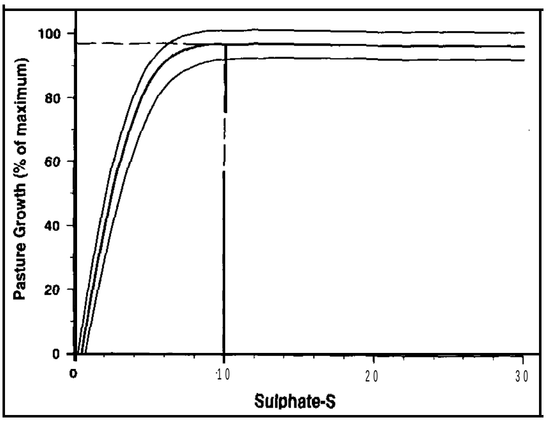
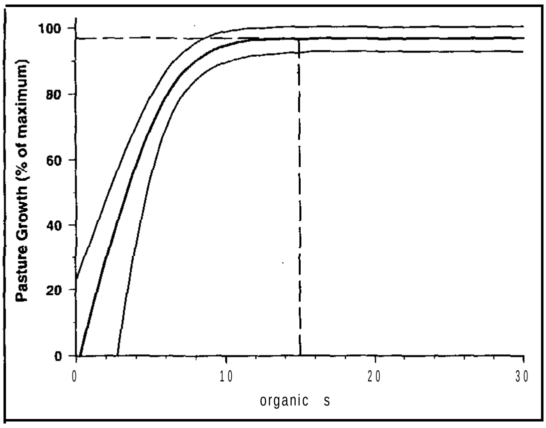


Figure 7 The relationship between relative pasture production and organic S for all soils.



soils in other areas of New Zealand provide considerable amounts of K for plant growth which is provided from the continual weathering of soil clay minerals; they also contain plant-available but non-exchangeable K (not assessed by QTK). However, these sources of K are not thought to be significant in Northland soils.

Table 2 The K fertility status of Northland soils in 1989/90 and 1994/95

Quicktest K	1989/90		1994/95	
	Dairy	Sheep-beef	Dairy	Sheep-beef
≤ 8	66%	64%	73%	74%
9–10	14%	16%	11%	12%
11+	20%	20%	17%	14%

Sulphur

Two soil tests are used to assess the S status of soils: the sulphate-S test (Saunders et al. 1981), used to measure immediately available S, and the extractable organic-S test (Watkinson *et* al. 1991), which measures more slowly available S. Research results show that there are universal relationships between relative pasture yield and the two S tests for all soil groups (Figures 6 and 7). The biological optimum soil test values are IO and 15 for sulphate-S and organic-s respectively, giving target ranges of 1 O-l 2 for sulphate-S and 15–20 for organic-S. In 1989/90, only 38% of dairy farm samples and 29% of sheep-beef farm samples had a sulphate-S level of *greater* than 10% whereas *this* had *risen to 53%* and 39% respectively by 1994/95 (Table 3). This increase in S levels is consistent with the increase in P levels shown earlier (Table 1) and suggests that, generally, fertilisers containing both P and S have been applied.

As the organic S test has been commercially available for only the last two years, there are no comparative data for this test.

However, the two tests should be used in conjunction with each other. Low levels for both tests indicate a need for capital application of S fertiliser, and high levels indicate maintenance S is required.

Field trial results show that S deficiencies may be overcome with moderate S inputs, provided the form of S (either sulphate or elemental S) appropriate to the individual farm is applied. The average amount of S required to overcome a deficiency on volcanic soils is 25 kg S/ha (range 20–30). This *amount* of S *is* equivalent to 2 10 kg/ha superphosphate. For sedimentary soils 35 kg S/ha (range 30-40) is required, which is equivalent to 290 kg/ha superphosphate.

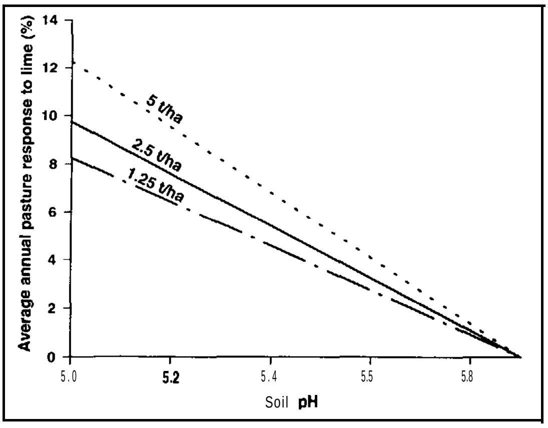
Table 3 The S fertility status of Northland soils in 1989/90 and 1994195

Sulphate-S	1989/90 Dairy	1989/90 Sheep-beef	1994/95 Dairy	1994/95 Sheep-beef
≤ 9	62%	71%	47%	61%
10+	38%	29%	53%	39%

Soil pH

Liming agents are applied to increase soil pH. As soil pH increases, in general, the size of the response to liming decreases. For example, at pH 5.0 pasture production increases by 8–12%, depending on rate of lime application, while at pH 5.8-6.0 responses are minimal (Figure 8). This general relationship could be modified somewhat by the local situation as demonstrated elsewhere in this proceedings (O'Connor & Hunt 1996). The biological optimum for mineral soils is pH 5.9 and the target range is pH 5.8-6.0. In general, liming soils with a pH greater than 6.0 will have little or no benefit for pasture production.

Figure 8 The relationship between the increase (%) in annual pasture production as a result of liming and soil pH.



Since 1989/90 soil pH on dairy farms has increased, only 15% of these samples being pH 5.5 or less in 1994/95 compared with 38% 5 years earlier (Table 4). There has been no change in soil pH status on sheep-beef farms.

In Northland, as in other areas, at pH < 5.0 responses to lime will occur, mainly through aluminium (Al) toxicity being reduced, and at pH 5.0-5.5, again by Al toxicity being reduced and also by previously unavailable molybdenum (Mo) being released and increasing clover production and function. At pH 5.5-6.0, lime responses are mainly due to increasing N mineralisation (through stimulation of soil micro-organisms) and further increases in Mo availability. Some Northland soils will respond to fertiliser Mo.

Table 4 The pH status of Northland soils in 1989/90 and 1994/95

Soil pH	1989/90 Dairy	1989/90 Sheep-beef	1994/95 Dairy	1994/95 Sheep-beef
≤ 5.5	38%	29%	15%	29%
≤ 6.0	62%	71%	85%	71%

Maintaining soil fertility

Capital applications of fertiliser nutrients are essential in Northland to raise soil fertility to the target ranges for the various soil tests. Once reached, the amounts of nutrients required to maintain soil test levels within the target ranges are the amounts needed to replace the losses of nutrients from livestock or their products leaving the farm, dung and urine deposited in gateways and stock camps, and the inevitable losses of nutrients that occur in soils. Therefore, nutrient losses at maintenance vary predominantly as a function of stocking rate and soil properties, as shown for daitying (Table 5) and sheep-beef farming on sedimentary soils (Table 6).

Table 5 Maintenance nutrient requirements (kg/ha) in relation to stocking rate for dairying on sedimentary soils.

Stocking rate (cows/ha)	Maintenance rate P	K	S
2	22-26	20-30	20-23
3	36–41	40-50	27-32
4	52-59	60-70	37–42

* 1 cow = 350 kg liveweight producing 290 kg milksolids

Table 6 Maintenance nutrient requirements (kg/ha) in relation to stocking rate for sheepbeef farming on sedimentary soils.

Stocking rate (s.u./ha)	Maintenance rate P	K	S
7	6-12	17-21	6-13
10	10–16	22-28	8-19
13	15-22	27-35	10–23
16	21-28	32-41	13-27

It should be noted that the above guidelines are nutrient rates estimated to maintain near-maximum pasture production. The newly available decision support software Outlook™ gives estimates of nutrient requirements at any level of pasture production.

Economic versus biological optimum soil test levels

The biological optimum soil test range values assume a farmer's objective is to grow near maximum pasture production. The economically optimum soil test levels will depend on the individual farm in terms of both physical and financial factors. As a general rule, as gross farm income increases so the economic optimum soil test level will become closer to the biological optimum. For example, at current costs and prices intensive dairy farmers on volcanic soils around Kerikeri could justifiably raise soil fertility to the target range for near-maximum pasture production (thereby embracing the biological optimum). In contrast, extensive sheep and beef farmers on sedimentary soils around Waiotira may find themselves farming at soil test levels below the biological optimum, but the main aim should be to improve pasture production on the better part of the farm by increasing soil fertility towards the biological optimum, while maintaining production on the remainder of the farm.

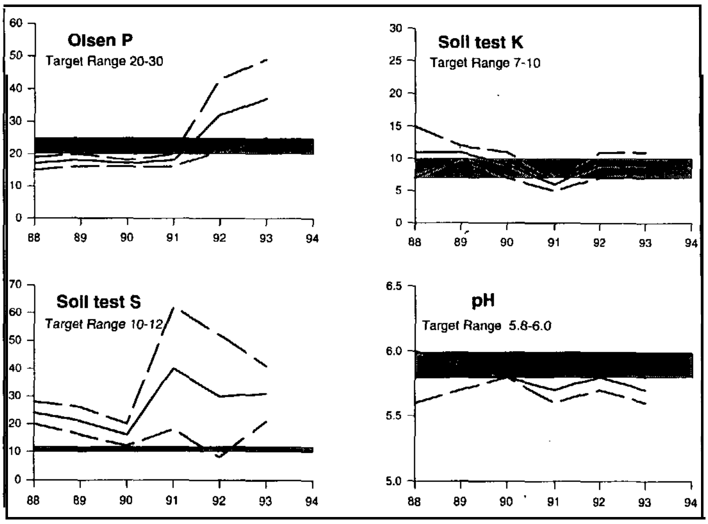
Again, the decision support software Outlook™ enables consultants and farmers to explore various fertiliser strategies to optimise farm production objectives with economic fertiliser application.

On-farm monitoring of fertiliser policies

All of the above information, while based on large amounts of trial information, does represent the **average** situation as derived from the available research information. The experimental evidence varies considerably and this variation will mean that many individual farm properties will have nutrient requirements which lie outside the average requirements as described above. It is for this reason that farmers should set up their own soil test monitoring programme. Maximum advantage from soil analysis will be achieved by a consistent programme of repeated testing over a number of years and in this way a picture of the trends in soil fertility status of the farm will be built up and adjustments to the fertiliser programme made accordingly.

A soil fertility monitoring programme consists of areas of the farm divided on the basis of soil type, topography and grazing management, with permanently identified sampling lines set up in each area. Soil samples should then be collected from each sampling line every 2 to 3 years in the same month and the average soil test results graphed to examine the trends (Figure 9). In general, while soil test levels will vary from year to year, if the test level remains constant over several years, the fertiliser policy will be maintaining the current situation. A declining or increasing trend in soil test levels will indicate that levels of fertiliser being applied are either insufficient or greater than required, respectively.

Figure 9 An example of the results of a soil test monitoring programme on a Northland dairy farm (volcanic soils).



Summary

The engine-room of grassland production is the soil resource. Northland soils are in general of low fertility and require capital inputs of fertiliser and lime. As indicated by soil test data, there is considerable room for improving pasture production by increasing soil fertility. Maintenance rates of fertiliser should not differ markedly from those in other areas, ***provided*** optimum soil test levels have been achieved. The main soil fertility requirements for Northland soils, in priority order are: P, lime, S, K and Mo.

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