Long-term changes in soil fertility in hill country

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Abstract

It has been more than 10 years since the last comprehensive soil sampling of the long term phosphorus (P) fertiliser and sheep grazing farmlet study established at the AgResearch Ballantrae Hill Country Research Station in 1975. This paper reports the findings from a sampling in October 2014 of the soils in the farmlets that have had no fertiliser since 1980 (LFNF), received 125 kg/ha/year of superphosphate since 1980 (LFLF) or 375 kg/ha/year of superphosphate since 1980 (HFHF). Increases in total P levels in the soil reflect the differences in P inputs between the LFNF, LFLF and HFHF farmlets over the last 40 years. In sharp contrast total sulphur (S) levels in soils have showed little change, despite the large amounts of sulphur applied in superphosphate each year. Exchangeable calcium (Ca) levels have increased on the farmlets receiving fertiliser, reflecting the Ca inputs in superphosphate, while magnesium (Mg) levels are lower in the HFHF farmlet. Potassium has shown little change, with the exception of increases on low slope areas in the HFHF farmlet. Olsen P levels have not changed in the topsoil (0-75 mm) in the HFHF since the 2003 sampling, despite annual P inputs in excess of maintenance. The absence of any change might be explained by the finding that P is accumulating in large amounts in the 75-150 mm soil depths on low slopes in the HFHF farmlet. This finding was unexpected serving to highlight the insights these long-term experimental studies provide to both science and industry.

Keywords: Long term fertiliser study, P fertiliser, Olsen P, soil fertility

Key message

- Long-term fertiliser and sheep grazing field studies are an invaluable resource for both science and the industry.

Introduction

The long term fertiliser and sheep grazing farmlet study established at the AgResearch Ballantrae Hill Country Research Station in 1975 provides invaluable insights into the interactions between phosphorus (P) fertiliser use, soil fertility and biology, and pasture and animal production (Clark *et al.* 1990; Mackay & Lambert 2011). Only the 'Irrigation and Fertiliser study' at AgResearch Winchmore Research Station has been in place longer (Smith *et al.* 2012). Since detailed monitoring at Ballantrae ceased in 1990, the fertiliser treatments have been maintained, along with nominal sheep stocking rates and grazing practices. An update of the changes in sheep stocking rate and soil fertility was reported by Mackay & Lambert (2011), with the findings at that time also compared with earlier published data from this long-term site (Lambert *et al.* 1990). Since 1980, 130+ research and conference publications have reported on studies utilising the long-term fertiliser and sheep grazing study at Ballantrae, and a SCOPUS® database analysis revealed these have been cited more than 750 times. This field site provides one of the few opportunities to track ongoing changes in the chemistry, biology and physical properties of soils, the fate of contaminants from fertiliser, pasture composition and performance, changes in pest and weeds through to animal production.

This paper reports the findings from a sampling in October 2014 of the soils on the farmlets that have had no fertiliser since 1980 (LFNF), received 125 kg/ha/year of superphosphate since 1980 (LFLF) and received 375 kg/ha/year of superphosphate since 1980 (HFHF). It has been more than 10 years since the last comprehensive soil sampling of the long term fertiliser and sheep grazing farmlet study.

Materials and methods

Field location

The study was conducted at the AgResearch Ballantrae Hill Country Research Station, Southern Hawke's Bay, New Zealand (408180S, 1758500E). Ballantrae, typical of much of the North Island's steep, pastoral hill country covering 3.5 million ha (28% of the total area of farmland in New Zealand), is located 125 to 350 m above sea level with an average air temperature of 12.8°C and annual rainfall of 1270 mm distributed evenly throughout the year. Brown and Pallic Soils (Hewitt 1998) are present i.e. yellow-brown earths and intergrades to yellow-grey earths, and related steepland soils, mainly formed from tertiary sandstone, siltstone, and mudstone, but with some loess influence in areas.

Long term fertiliser and sheep grazing study (1975-2014)

Self-contained experimental farmlets, two receiving low (LF) and two receiving high (HF) fertiliser inputs were established in 1975 (Lambert *et al.* 1990).

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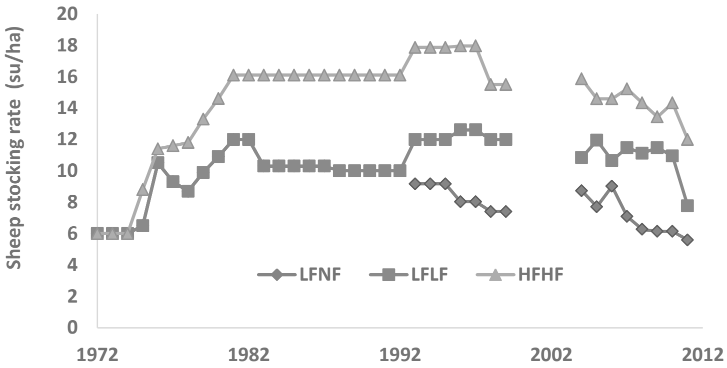

Figure 1 Nominal sheep stocking rates (su/ha) on the farmlets that has had no fertiliser since 1980 (LFNF), received 125 kg/ha/year of superphosphate since 1980 (LFLF) or 375 kg/ha/year of superphosphate since 1980 (HFHF) (Mackay & Lambert 2011).

Since 1980, one of the LF farmlets has received 125 kg superphosphate/ha/year and has been stocked by sheep at 10.6 su/ha (LFLF); one of the high fertiliser farmlets has received 375 kg SSP/ha/year and has been stocked at 16.0 su/ha (HFHF). Since 1980 fertiliser has been withheld from one of the low (LFNF) fertiliser farmlets. Ground limestone was applied on the HFHF pasture in 1975 (1250 kg/ha) and in 1979 (2500 kg/ha). Nitrogen (N), as urea, was applied to HFHF in 1975 at 20 kg /ha. The farmlets are continuously grazed by breeding ewes, with replacements introduced in the autumn.

Measurements and analysis

Occasional measurements of soil fertility and pasture production have been made on the farmlets since detailed monitoring ceased in the late 1980s. Since then the objective has been to maintain sheep stocking rates close to 10.6 and 16.0 su/ha on the LFLF and HFHF farmlets, respectively, with annual superphosphate inputs of 125 and 375 kg/ha/year, respectively (Figure 1). Sheep stocking rates have slowly decreased on the LFNF farmlets since the early 1990s (Figure 1). Sheep grazing has been a combination of set-stocking with some rotational grazing within each farmlet in the last 15 years.

In October 2014, soil samples were taken to two depths (0-75, 75-150 mm) from 18 sites from each of the LFNF, LFLF and HFHF farmlets. The 18 sites in each farmlet covered three slope classes (low (0-12°), medium (13-25°) and steep (>25°)) and three aspects (centred on the North East, North West and South) and two replicates. Bulk density was assessed at the time of sampling at all sites. Soils were analysed for total P, S, C and N, pH in water, Olsen P, exchangeable cations and sulphate-sulphur using a commercial laboratory.

Results and Discussion

Changes in total phosphorus, sulphur, carbon and nitrogen

Differences in total P in the soil reflect the difference in P fertiliser inputs over the last 40 years (Table 1). For example, total P in the 0-75 mm and 75-150 mm soil depths averaged across the three slopes and three aspects of the HFHF farmlet averaged 867 and 619 µg/g, respectively, compared to 357 and 311 µg/g in the same two depths in the LFNF farmlet (Table1). In sharp contrast and consistent with the findings of Saggar *et al.* (1990), there was little accumulation of S in the soil profile, despite the addition of 14 and 41 kg S/ha/year in the 125 and 375 kg superphosphate, respectively, applied each year. Total S in the 0-75 and 75-150 mm soil depths averaged across the three slopes and three aspects in the HFHF farmlet averaged 490 and 397 µg/g, respectively, compared to 450 and 387 µg/g in the same two depths in the LFNF farmlet (Table 1). Saggar *et al.* (1990) estimated that close to 70% of the applied S is lost by leaching in this low anion storage capacity sedimentary soil. The limited accumulation of S in this soil, which in these hill soils is in the organic fraction, is a function of the amount of organic N that is also accumulating. There are few differences in total soil N or C contents between the farmlets despite large differences in primary production. More detailed discussion of the long-term influence of fertiliser and grazing on soil C and N is beyond the scope of this paper.

Changes in bulk density, pH, sulphate-S and exchangeable cations

Bulk density in the topsoil (0-75 mm) across the three slopes and aspects for each of the LFNF, LFLF and

Table 1 Total phosphorus (P) and sulphur (S) (*µ*g/g) in the 0-75 mm and 75-150 mm soil depths averaged across the three slopes and aspects for the farmlets that has had no fertiliser since 1980 (LFNF), received 125 kg/ha/year of superphosphate since 1980 (LFLF) or 375 kg/ha/year of superphosphate since 1980 (HFHF).

Nutrient	Soil depth (mm)	LFNF	LFLF	HFHF
Total P (*µ*g/g)	0-75	357	433	867
	75-150	311	335	619
Total S (*µ*g/g)	0-75	450	466	490
	75-150	387	377	397

HFHF farmlets averaged 0.75, 0.74 and 0.72 Mg/m^3, respectively, with the trend for higher bulk density on the low slope areas of HFHF compared to the other two farmlets. Soil pH levels in the topsoil (0-75 mm) across the three slopes and aspects for each of the LFNF, LFLF and HFHF farmlets averaged 5.5, 5.4 and 5.2, respectively. These are higher than the soil pH values reported by Lambert *et al.* (2000) of 5.0 and 5.15, for the LFLF and HFHF farmlets, respectively, in 1987, despite no lime having been applied to the farmlets since small amounts were applied to the HFHF farmlet in 1975 (1250 kg/ha) and again in 1979 (2500 kg/ha). Average sulphate-S levels in the topsoil (0-75 mm) for the three slopes and aspects in the LFNF, LFLF and HFHF farmlets were 6, 9 and 11 µg/g, respectively. These reflected the fact that the LFLF and HFHF farmlets received annual S inputs in the superphosphate application.

Average quick test Ca levels in the topsoil (0-75 mm) for the three slopes and three aspects in the LFNF, LFLF and HFHF farmlets were 2.7, 3.6, and 4.7 µg/ml, respectively, reflecting the fact that considerable amounts of Ca are applied in single superphosphate. The applications of 125 and 375 kg superphosphate/ha/year adds 25 and 75 kg Ca/ha, respectively. Re-distribution of this divalent cation, along with exchangeable potassium (K) is also evident, as is some depletion of K on steep slopes in the HFHF farmlet. Generally, there was little difference in quick test K levels across the farmlets. The exception was high K levels on the low slope areas in the HFHF farmlet. Exchangeable Mg levels declined on all slope classes in the HFHF farmlet, with the average for the farmlet at 16 µg/ml, compared with 22 and 21 µg/ml for the LFLF and LFNF farmlets, respectively. The soil Mg levels in the HFHF farmlet were below the optimum for livestock (20-25), but above the levels where a pasture response (>10 µg/ml) would be expected. The loss of Mg is the result of a combination of factors, including nitrate and SO$_4$-S leaching losses. Sakadevan *et al.* (1993) found the losses of sulphate-S to be 10 times higher than nitrate in drainage water below 250 mm soil depth. The high losses of S from the LFLF and HFHF farmlet explains why little S has accumulated in these soils over the last 40 years.

Changes in soil phosphorus fertility

The Olsen P levels in soil on the farmlet that has had no fertiliser since 1980 has dropped to 4 µg/ml (Figure 2), ranging now from 2 to 7 µg/ml across the 18 sites in the farmlet. The farmlet that has received 125 kg/ha/year of superphosphate since 1980 (LFLF) averages 13 µg/ml (range 3-26 µg/ml) and the farmlet that has received 375 kg/ha/year of superphosphate since 1980 (HFHF) averages 49 µg/ml (range 10-106 µg/ml).

In the LFLF farmlet the annual application of 125 kg superphosphate/ha/year has resulted in little change in Olsen P values, indicating the P fertiliser input is just balancing the P losses to soil, in product and by animal transfer within the paddock. This is matched by the fact there has been no change in the nominal long term average sheep stocking rate on the farmlet since 1980 (Mackay & Lambert 2011). Until annual inputs are increased above maintenance no improvements in production are going to occur.

On the LFLF farmlet the average Olsen P values for the low, medium and high slope classes, were 25, 9 and 7 µg/ml, respectively (Figure 3). In a commercial operation where the goal is to optimise the use of the land resource, the annual P fertiliser input to the LFLF farmlet would be increased to lift the Olsen P closer to >20 ug/ml on the medium slope based on the sampling protocol and target Olsen P level for 97% maximum pasture production in the recommendations of Morton & Roberts (2009). Lambert *et al.* (2014) using pasture and soil data collected from the long term fertiliser and grazing study at Ballantrae from 1975 to 1998, found that the Olsen P level for 97% maximum pasture production was closer to 14-15 µg/ml. The apparent difference in the critical Olsen P level between the two studies might reflect the fact that the calibration curve reported by Lambert *et al.* (2014) was from a single site, while the calibration curve reported by Morton & Roberts (2009) comes from a large number of sites.

On the HFHF farmlet with Olsen P values averaged 88, 34 and 27 µg/ml on the low, medium and high slope

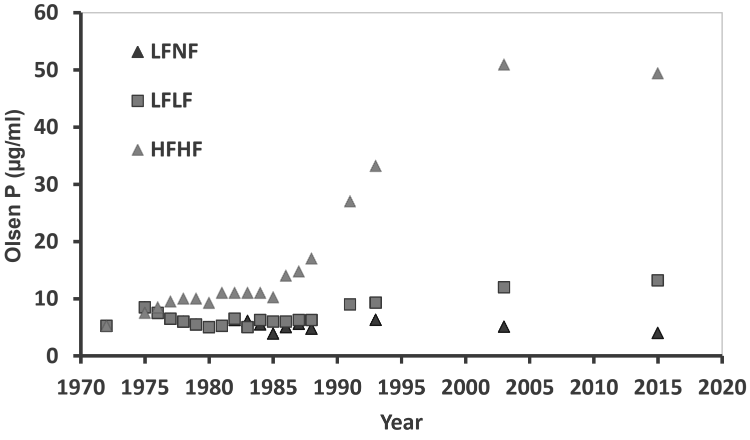

Figure 2 Changes in soil Olsen P levels (µg/ml) in the 0-75 mm soil depth in the farmlets that has had no fertiliser since 1980 (LFNF), received 125 kg/ha/year of superphosphate since 1980 (LFLF) or 375 kg/ha/year of superphosphate since 1980 (HFHF).

classes, respectively (Figure 3), the recommendation if running a commercial operation, would be to reduce the superphosphate inputs by 100-125 kg/ha/year, to bring the Olsen P values below 30 and closer to 20. This would also reduce the risk of P losses in surface run-off (Parfitt *et al.* 2009). In the LFNF farmlet the average Olsen P levels were < 5 µg/ml on all slope classes (Figure 3), indicating a soil sample from any slope would be informative of the likely behaviour of the system to added P fertiliser.

The Olsen P levels in the soil in the HFHF farmlet have not increased since the last sampling in 2003 (Figure 2). Based on the Morton & Roberts (2009) claim estimate of the amount of P above maintenance required (4-7 kg P/ha) to raise the Olsen P test by 1 unit for these soils should have translated into an increase of 10-20 units on the HFHF farmlet over the last decade. Lambert *et al*. (2000) observed that before 1990 the increase in Olsen P levels were lower and slower than predicted from the model used by Morton & Roberts (2009). Lambert *et al.* (2000) assumed the discrepancy was because the grazing trial soils had a very limited previous fertiliser application history. Interestingly, while the changes in Olsen P levels on the HFHF farmlet from 1990 to 2003 aligned more closely with the changes predicted by the Morton & Roberts (2009) model, the lack of changes in soil test values over the last 10 years (2003-2014) is more difficult to explain given that as the initial Olsen P level increases, less soluble P is required to increase the Olsen P by 1 unit (Edmeades *et al.* 2006).

Changes in soil phosphorus fertility with depth

Olsen P levels in the 75-150 mm soil depths in the low slope areas of the HFHF farmlet were higher than in the topsoil (0-75 mm) of either the LFLF or LFNF farmlets (Figure 3). This was a trend also noted at the sampling of the farmlets in 2003. Phosphorus, unlike nitrate-N is a specifically absorbed anion, and as a consequence has little mobility in soil accumulating in the topsoil. The exception would be in coarse textured soils, soils with low anion storage capacity, like podzols (Edwards *et al.* 1994) or where preferential flow occurs. The possible mechanisms for P movement down the profile in this study includes plant roots, inorganic and organic P movement (dissolved organic matter) in soil solution, P sorbed on clay minerals washed down cracks and channels as a consequence of preferential flow, and the incorporation and mixing of fertiliser material, plant litter and topsoil by earthworms. The movement of P to depth might explain in part the slower than predicted increase in Olsen P values in the top 75 mm of soil in the HFHF farmlet from the 1.4 times maintenance P applications over the preceding decade. The size of the increases in the Olsen P levels at the 75-150 mm depths challenges the notion that P is largely immobile and only

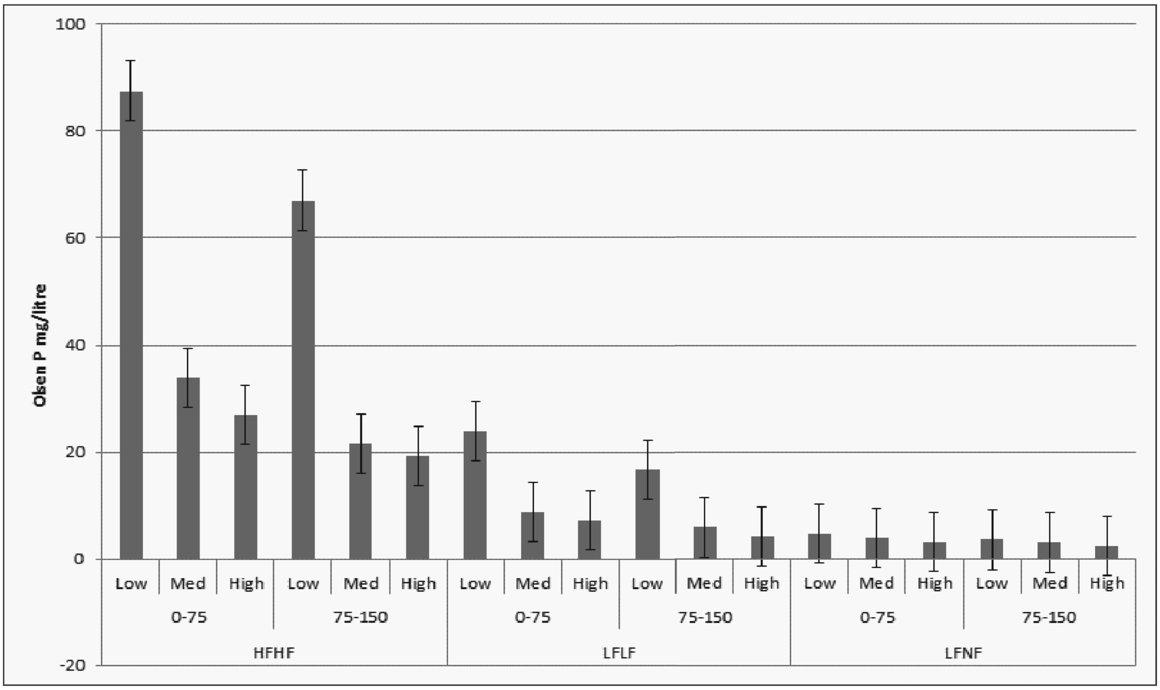

Figure 3 Changes in Olsen P levels (*µ*g/ml) at 0-75 and 75-15 mm soil depths on low, medium and high slope areas on the farmlet that has had no fertiliser since 1980 (LFNF), received 125 kg/ha/year of superphosphate since 1980 (LFLF) or 375 kg/ha/year of superphosphate since 1980 (HFHF). Vertical lines are errors bars.

small amounts of this nutrient move down through the profile. Into the future some thought might need to be given to increasing the depth of sampling to track and capture the changes in P levels in high P fertility systems.

Conclusions

Field sites with well documented, long-term diverse management histories, like the long term fertiliser and sheep grazing study at Ballantrae provide invaluable insights into the behaviour of our pastoral ecosystems beyond current knowledge, boundaries and calibrations. The longer these studies are run the more valuable they become.

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