Long-term changes in soil fertility and pasture production under no, low and high phosphorus fertiliser inputs

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Abstract

Many hill country farmers have struggled to maintain fertiliser inputs in recent years. The long-term fertiliser and sheep grazing farmlet study at the AgResearch Ballantrae Hill Country Research Station provides invaluable insights into the benefits of continued annual inputs of phosphorus (P) fertiliser on production levels and the farm business, and also the implications to the production system when fertiliser is withheld. Since detailed monitoring stopped in 1990, the fertiliser treatments have been maintained, along with nominal sheep stocking rates and grazing practices. Occasional measurements of soil fertility have also been made on the farmlets that have received either no fertiliser inputs for 30 years, a low annual fertiliser input (125 kg superphosphate (SSP)/ha/yr), or a high input (375 kg SSP/ha/yr) for 35 years. In this paper changes in sheep stocking rate and soil fertility are reported and compared with earlier published data from this long-term site. This field study provides a valuable resource for ongoing research into nutrient requirements and cycling in hill land environments, and a visual demonstration of the continued importance of fertiliser application as a driver of hill country production.

Keywords: Livestock production, P fertiliser, Olsen P, long-term sites

Introduction

Many hill country farmers have struggled to maintain fertiliser inputs in recent years (Davidson 2010). The influence of withholding fertiliser on pasture and animal production and economic returns was the subject of a series of papers presented at the 1990 Grassland Conference (Clark *et al.* 1990; Gillingham *et al.* 1990; Lambert *et al.* 1990; O'Connor & Smart 1990; Rowarth & Gillinghan 1990). The key message from that conference was that withholding fertiliser offers a short-term strategy for reducing expenditure, but the opportunity cost of not applying fertiliser increased with time, and the higher the initial soil fertility the greater the opportunity cost.

The ability of scientists to report on the long-term consequence of a change in the fertiliser use on pasture and animal production was based on access to the findings from a series of long-term fertiliser and grazing studies. In that regards the long-term fertiliser and sheep grazing farmlet study at the AgResearch Ballantrae Hill Country Research Station, dating back to 1972, and the Irrigation and Fertiliser study at AgResearch Winchmore Research Station, dating back to 1959, provide invaluable data sets on the long-term influence of phosphorus (P) fertiliser on soil fertility and biology, pasture ecology and animal production that is of interest to both science and producers. It also provides an invaluable field laboratory for extension.

This paper reports changes in sheep stocking rates and soil fertility on the long-term fertiliser and sheep grazing farmlet study at the AgResearch Ballantrae Hill Country Research Station, since last reported by Lambert *et al.* (2000). The paper also comments on the value of long-term field sites for science, teaching and extension.

Materials and Methods

Field location

The study was carried out at the AgResearch Ballantrae Hill Country Research Station, Southern Hawke's Bay, New Zealand (408180S 1758500E). The Research Station, typical of much of the North Island's hill country which covers 3.5 million ha (28% of the total farmland in New Zealand), is located 125 m to 350 m above sea level with an average air temperature of 12.8°C and an annual rainfall of 1270 mm evenly distributed throughout the year. The soils are of sedimentary origin originally formed under forest which was cleared and sown to grassland about 100 years ago.

Long-term fertiliser and sheep grazing study (1975-2011)

Self-contained experimental farmlets, two receiving low (LF) and two receiving high (HF) fertiliser inputs were established in 1975 (Lambert *et al.* 1990). Since 1980, one of the low fertiliser farmlets has received 125 kg superphosphate (SSP)/ha/yr and has been stocked by sheep at 10.6 su/ha, and one of the high fertiliser farmlets has received 375 kg SSP/ha/yr and has been stocked at 16.0 su/ha. Since 1980 fertiliser has been withheld from one of the low and one of the high fertiliser farmlets. Data are not presented for the high fertiliser farmlet where fertiliser has been withheld since 1980. Ground limestone was applied on the HF pasture in 1975 (1250 kg/ha) and in 1979 (2500 kg/ha). Nitrogen, as urea, was applied to HF in 1975 at 20 kg N/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 was stopped in the late 1980s, and since that time annual SSP inputs of 125 and 375 kg/ha have been maintained. Nominal sheep stocking rates of 10.6 and 16.0 su/ha have been maintained on the LF and HF farmlets, and have been slowly decreased on the LF farmlet that has received no fertiliser since 1980 (Fig. 1). Sheep grazing has been a combination of set stocking and rotational grazing during this period. In 1993 soil samples (0-75 mm) to assess soil fertility were taken from 18 permanently marked sites on each of the three farmlets. The 18 sites cover three slope classes (low, medium and steep) and three aspects (centred on the North East, North West and South aspects) and are replicated twice. In 2003 the exercise was repeated with soil sampling taken to three soil depths (0-75, 75-150, and 150+ mm). On low slopes soil samples were taken to a depth of 300 mm, while on some steep slopes the soil profiles did not extend beyond 150 mm.

Results and Discussion

Changes in soil fertility

Soil Olsen P on the farmlet receiving 375 kg SSP/ha/yr increased nearly 2 µg/ml/yr from 1987 to 2003, reflecting annual P inputs consistently 1.4 times or an additional 10 kg P/ha/yr above maintenance requirements (Fig 2). In comparison, soil Olsen P showed little change on the farmlet receiving annual inputs of 125 kg SSP/ha over that period. Where no fertiliser has been applied since 1980 the Olsen P had declined to 6 µg/ml in 2003. In 2003 the standard deviation and (co-efficient of variation) for Olsen P values across all slopes and aspects on the NF, LF and HF farmlets were 1.8 (36%), 5.7 (44%) and 26 (50%), respectively, decreasing to 2.1 (38%), 4.3 (26%) and 16.4 (34%), respectively, when analysis was limited to the six samples taken from moderate slopes on each farmlet, the slope class targeted for routine soil fertility monitoring in hill country (Morton & Roberts 1999). The redistribution of P in dung by the grazing animal, the major determinant of P requirements in grazed pastures, is apparent with P accumulating on the low slope areas (Fig. 3). Despite the low mobility of the P ion, soil Olsen P levels in the HF farmlet are elevated below 15 cm (Fig. 3). The distribution of P across the slope classes highlights the importance of sampling the average slope in hill country when assessing soil fertility.

In comparison to the accumulation of P in the topsoil, sulphate-sulphur (SO_4-S), a non-specifically sorbed anion, has not accumulated in the topsoil, despite the addition of 14 and 41 kg S/ha/yr in superphosphate in the LF and HF, respectively, since 1975. 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. This is evidenced by the accumulation of SO_4-S at depth in the HF farmlet (Fig. 3). Interestingly, Mackay *et al.* (1988) found that pastures on these soils are only responsive to added S when it is applied with P, even in situations where superphosphate has been withheld for a number of years.

Soil pH averaged 5.0 and 5.1 on the LF and HF farmlets, respectively, in 1993, comparable to levels reported by Lambert *et al.* (2000) of 5.0 and 5.15, respectively, in 1987. In the 2003 sampling, soil pH was 5.3 on both the LF and HF farmlets. There was very little variability in soil pH, with coefficients of variation of < 4%. Care must be taken in comparing these values with those reported by Lambert *et al.* (2000) as in this paper data are limited to one LF and one HF farmlet. In Lambert *et al.* (2000) data are for a total of 10 farmlets.

It is often forgotten that with the applications of 125 and 375 kg SSP/ha/yr comes the addition of 25 and 75 kg calcium (Ca)/ha/yr, respectively. Re-distribution of this cation, along with exchangeable potassium (K) is also evident, with some evidence for some depletion of K on steep slopes under HF (Fig. 3). Exchangeable Mg levels have declined on all slope classes below 15 cm soil depth on the HF farmlet. In 2003 the standard deviation and (co-efficient of variation) for exchange Mg across all slopes and aspects on the NF, LF and HF farmlet were 4.4 (19%), 6.2 (27%) and 4.0 (23%), respectively. The soil Mg levels are below the optimum for livestock (20-25), but above the levels where a pasture response (>10) would be expected. The loss of Mg is associated with SO_4-S leaching losses, which was found by Sakadevan *et al.* (1993) to be 10 times higher than nitrate in drainage water below the 250 mm soil depth.

Earthworms

Lambert (1986) reported earthworm numbers in 1979 of 526 and 644/m^2, under LF and HF, respectively, with *Aporrectodea caliginosa* the dominant species. Earthworm mass was 24% higher in LF than HF, and at that time the LF and HF farmlets carried 9.9 and 13.3 sheep su/ha, respectively. Lambert *et al.* (1996) found earthworm mass was 74% higher for the HF than for the LF treatment in 1994, when the stocking rate differential

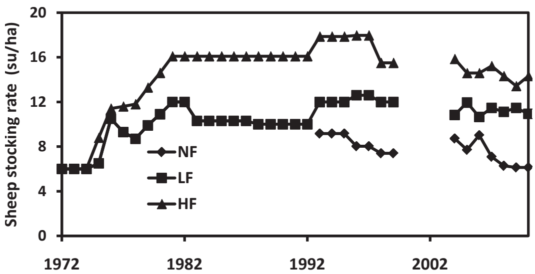

Figure 1 Nominal sheep stocking rates (su/ha) on the no fertiliser (NF), low fertiliser (LF) and high fertiliser (HF) farmlets.

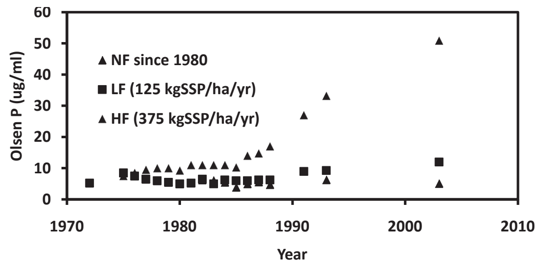

Figure 2 Changes in soil Olsen P levels (µg/ml) on the no fertiliser (NF), low fertiliser (LF) and high fertiliser (HF) farmlets during 1970 to 2003

(10.6 vs. 16.0) was higher. Recently Schon *et al.* (2008) found similar earthworm numbers to the LF (580/m^2) farmlet in 1979, but higher numbers on the HF (>1050/m^2), although only low and moderate slopes were sampled in the 2006 sampling. *Aporrectodea caliginosa* (84.3%) and *Lumbricus rubellus* (7.1%) dominated in the HF soil, while in the LF soils *A. caliginosa* (57.8%), *A. rosea* (25.3%), and *Octolasion cyaneum* (9.5%) made up the bulk of the community. Out of six detected earthworm species, two, *Octochaetus multiporus* and *Rhododrilus robustus*, were endemic New Zealand species; the rest were cosmopolitan introductions. Springett *et al.* (1998) reported that the endemic species favour low fertility and low sheep stocking rates, with abundance and biomass declining with increasing soil fertility and stocking rate. There is a view held by some rural commentators that superphosphate application is detrimental to soil biological activity. The earthworm monitoring at Ballantrae has not supported this view.

Pasture performance

Pasture composition on the LF treatment is dominated by low fertility tolerant grasses such as browntop (*Agrostis capillaris*), with the ryegrass (*Lolium perenne*) content less than 10% (Lambert *et al.* 2003). On the HF treatment, ryegrass content is close to 50%, although the low fertility tolerant grasses still constitute a significant part of the sward. Subsequent analysis of pasture production data from the 1975/76 to 1986/87 period (Lambert M.G. unpublished) found that winter growth rates were proportionately greater for the HF than LF farmlets (45%), with the spring and summer-autumn production increase being proportionately smaller (31 and 36-37%, respectively). This has important positive implications in terms of reducing the imbalance between animal demand and pasture supply in both the slow and fast growth times of the year. In some earlier (1970-73) mowing studies Grant *et al.* (1981) also found that fertiliser application increased the proportion of annual growth over the winter and reduced the proportion in summer-autumn, in ryegrass, browntop and resident pastures. De Pino (1994) reported an increased contribution to annual yield from the autumn and winter growth as soil P levels increased. These finding are at odds with much of the published literature, which suggests little change in seasonal contribution as total yield increases with improving soil fertility. Interestingly, despite large differences in pasture composition and soil fertility, pastures on the LF and HF farmlets responded similarly to added fertiliser N (Lambert *et al.* 2003), indicating both are N deficient year round.

Fertiliser inputs, stocking rate and financial implications

Nominal sheep stocking rates of 10.6 and 16.0 su/ha have been maintained on the LF and HF farmlets, respectively, since 1980. The application of ground limestone applied on the HF pasture in 1975 (1250 kg/ha) and in 1979 (2500 kg/ha) may have contributed to the production differences in the 1980s.

Budgeted 2010-11 financial returns and costs for Central North Island hill country sheep and beef farms in MAF's annual monitoring programme were $65.71/su net cash income and $40.45/su farm working expenses, giving a cash operating surplus of $25.26/su. Based on these figures, a HF input system with stocking rate increased by 5.4 su/ha (the differential between HF and LF) would generate $354/ha extra net cash income which would be offset against extra farm working expenses (including increased superphosphate costs of $425/tonne applied and in addition extra direct expenses of $19.63/su) of $212/ha. This would increase the farm cash operating surplus by $142/ha or $90,200 for the 635 ha model farm. If only maintenance annual fertiliser inputs (i.e. 275 kg SSP/ha rather than 375 kg SSP/ha) were applied to the HF option (Morton & Roberts 1999), the increase in the annual farm cash operating surplus would be greater, i.e., $117,200.

In 1980, fertiliser was withheld from one each of the low and high fertiliser farmlets. Over the first 7 years of withholding fertiliser pasture production decreased 1.7% and 4.6% per year on the previously LF and HF

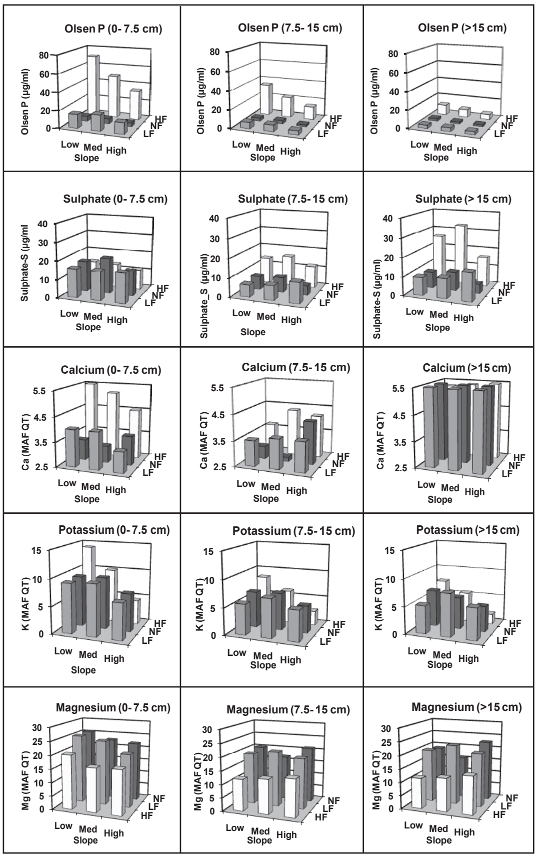

Figure 3 Soil Olsen P (µg/ml), sulphate-S and exchangeable Ca, K and Mg (MAF QT) on three slopes (low, medium and high) and three sampling depths (0-7.5, 7.5-15.0, 15.0) on the no fertiliser (NF), low fertiliser (LF) and high fertiliser (HF) farmlets in autumn 2003. (Note the change in the order of fertiliser history with magnesium.)

farmlets, resepectively (Lambert *et al.* 1990). Twenty years on, the low fertiliser farmlet which has not received fertiliser for 30 years is struggling to carry 6 su/ha, i.e., 62% of the LF stocking rate, and it is becoming very difficult to manage in terms of pasture utilisation. The growth of woody weeds has become a major challenge. While withholding fertiliser offers a short-term strategy for reducing expenditure, the opportunity cost of not applying fertiliser increases with time; the decrease in farm cash operating surplus between the LF and no fertiliser option, using a similar analysis to that outlined above for LF and HF and assuming similar levels of per animal performance, is estimated at $159/ha or $100,863 for the whole farm. This decline exceeds the annual farm profit before tax for the model farm budget.

Role of long-term field sites in research, teaching and extension

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. Publications include those investigating fertiliser and lime use (Lambert & Grant 1980), pasture species performance (Chapman *et al.* 1987), plant species diversity (Hopkins *et al.* 1993), N fixation (Lambert 1987), N response (Lambert *et al.* 2003), grazing management (Lambert *et al.* 1983), heavy metals (Loganathan *et al.* 1994), native and exotic invertebrates (Springett *et al.* 1998), nutrient run-off (Lambert *et al.* 1985), nitrate (Parfitt *et al.* 2009) and sulphate leaching (Sakadevan *et al.* 1993), C cycling (Saggar *et al.* 1997), fertiliser withholding (Lambert *et al.* 1990), soil invertebrate diversity (Parfitt *et al.* 2009) systems comparisons (Parfitt *et al.* 2004) and remote sensing (Kawamura *et al.* 2011).

The stored soil samples from the long-term site are used periodically by a range of science interests, as are the long-term data sets for soil chemistry, pasture production and species and meteorological parameters. This long-term 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 weed, and so on.

Over the last 20 years agricultural students from Massey University have made an annual visit to the long-term fertiliser and grazing study. Conservatively 10 post-graduate students have used the long-term fertiliser and grazing study as a field laboratory over the last 20 years. Presentations on the findings of the farmlets have been given to numerous groups over the decades. The long-term consequence of sub-maintenance P fertiliser inputs on pasture production and composition and animal performance, alongside blocks that have maintenance and capital fertiliser inputs, provide very powerful visual images for visiting farmers of the link between fertiliser inputs and farm outputs.

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. These long-term trials are not only invaluable assets for research and development, but also very powerful extension resources that once closed cannot be replaced.

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