The farm-gate phosphorus balance of sheep grazing systems maintained at three contrasting soil fertility levels

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Abstract

Farm-gate phosphorus (P)-balance (P_{input} vs P_{output}) was measured in grazing systems managed without P-fertiliser (P0), by increasing soil P (1994-2000) and then maintaining it (2001-2006) at near-optimum soil P fertility (target Olsen P = 10-12 mg/kg; P1), by increasing soil P and maintaining it at supra-optimal P-fertility (target Olsen P = 20-25 mg/kg; P2), or by fertilising to a supra-optimal level before allowing a return to the near-optimal level by withholding fertiliser (P1*). Pastures were grazed with either 9 (SR9) or 18 sheep/ha (SR18). P-export was in liveweight gain. Although fertilised paddocks accumulated 89-93% of their P input (fertiliser+feed) over the whole experiment (1994-2006), this included P that was contributing to changes in soil fertility and P accumulating in sparingly-available pools. The efficiency of fertiliser use was better demonstrated by P-balance during the maintenance phase (2001-2006) where changes in soil fertility were small. When P contributing to soil fertility changes was accounted for, the accumulation of P in sparingly-available pools was 40-47 kg P/ha in P1 paddocks and 75 kg P/ha in P2 paddocks. Differences due to stocking rate were not significant. Although total P input and accumulation did not differ between P1*SR18 and P1SR18 paddocks, soil fertility was improving marginally in the P1SR18 treatment and declining in the P1*SR18 treatment. Managing paddocks at levels of soil P fertility higher than necessary proved costly because more P was required to both build and maintain high levels of soil fertility.

Introduction

P is a key input supporting high productivity in many temperate Australian pasture systems. However, it is used relatively inefficiently with much more P applied as fertiliser on farm than is exported in products. P is consequently accumulating in agricultural soils. P accumulation contributes to the overall improvement in soil P-fertility. However, global P resources are limited and peak P (when supply falls behind demand) is now predicted to occur by 2033 (Cordell et al. 2009) and it is possible that P accumulation in soil will become unaffordable. We examined the ‘farm-gate’ P balance of pasture grazed by sheep to assess how soil fertility management affected the accumulation of P in paddocks and the efficiency of fertiliser use.

Methods

Grazing systems

Pasture, comprised of phalaris (*Phalaris aquatica*), annual grasses and sub clover (*Trifolium subterraneum*) near Canberra, ACT was managed without P-fertilisation (P0), by increasing soil P (1994-2000) and then maintaining it (2001-2006) at near-optimum soil P fertility (target soil test P = 10-12 mg/kg [0-10 cm depth, Olsen et al. 1954]; P1), by increasing soil P and maintaining it at supra-optimal P-fertility (target Olsen P = 20-25 mg/kg; P2), or by fertilising to a supra-optimal level before allowing a return to near-optimal by withholding fertiliser (P1*). The soil was a yellow chromosol with a topsoil phosphorus buffering index (Burkitt et al. 2002) = 50. Pastures were grazed with either 9 (SR9) or 18 yearling Merino sheep/ha (SR18). Sheep were replaced annually.

Soil fertility management

Fertiliser P inputs were determined annually using a January/February soil test and the relationship developed during the experiment between P applied and change in the Olsen soil test (ΔOlsen P =

0.31*(kg P applied/ha) - 2.69; R^2 = 0.89). P was applied as close as feasible to the opening rain in autumn and mainly as triple superphosphate (21% P, 1% S). Occasionally, when equal amounts of P were to be applied, single- or Mo-superphosphate (9% P, 11% S) was applied to facilitate applications of S and Mo. Other nutrients were applied as needed to ensure that P (and N supply via clover) were the only soil fertility variables.

P-balance calculations

P-inputs were determined as the sum of P applied as fertiliser and P introduced in supplementary feed (oats 3.3, wheat 3.8, barley 4.0 g P/kg). P-outputs in fleece-free weight gain and wool growth were computed using equation 3.10 of CSIRO (2007) and a constant P content for harvested wool (0.24 g P/kg clean wool).

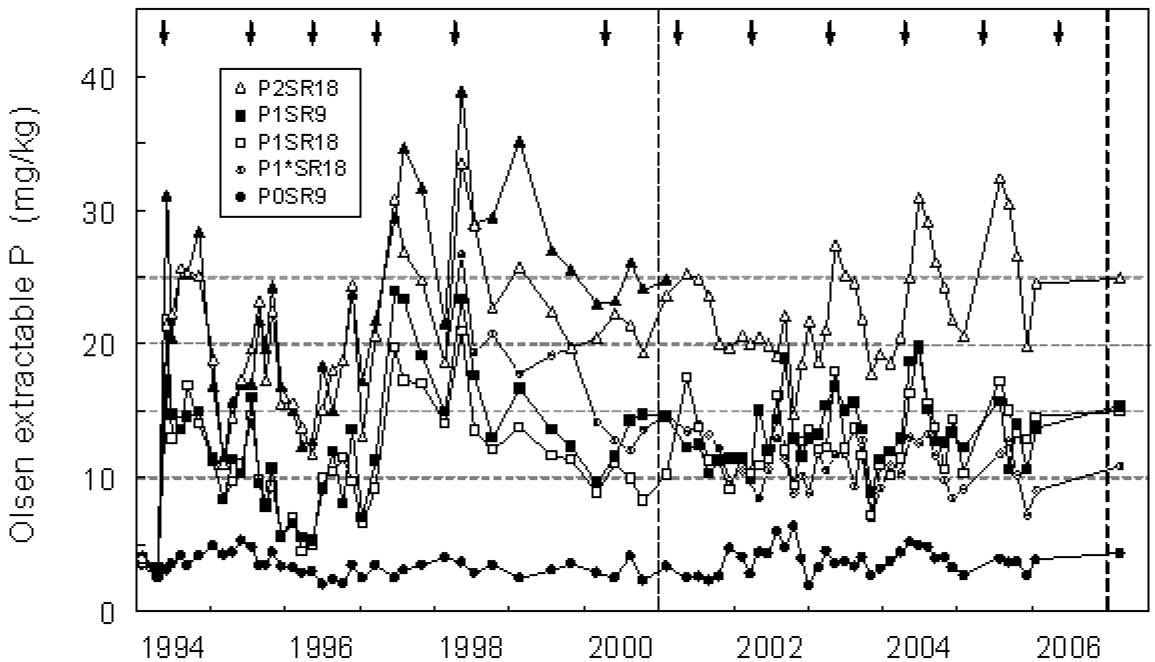

Figure 1. The extractable P concentration of topsoil (0-10 cm) in various grazing system treatments at Hall, ACT. Two phases of the experiment are delineated 1994-2000: a soil fertility build-up phase and 2001-2006: a soil fertility maintenance phase.

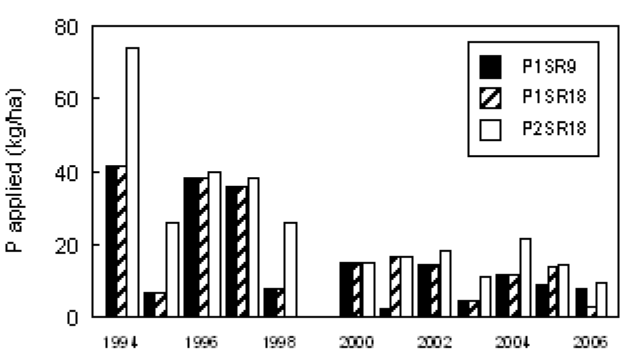

Figure 2. Amounts of P applied as fertiliser.

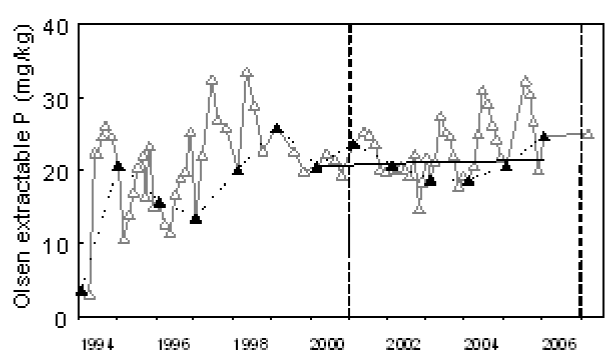

Figure 3. Temporal changes in soil P fertility in the P2SR18 treatment. Jan/Feb monitoring

points are shown as closed triangles.

Results

Soil fertility and grazing management

The P0 (unfertilised) pasture maintained an Olsen P level (0-10 cm) mainly in the range 2-5 mg P/kg (Fig. 1). The aim of the annual P-fertiliser applications was to lift soil fertility into the target range for each treatment and hold it there for as long as possible. Regular soil testing revealed the volatility inherent in soil fertility management. During the first few years of the trial this was in part due to difficultly estimating the amount of P to be applied, but it was also a product of the usual seasonal fluctuations in soil fertility. Initially relatively large amounts of P had to be applied to reach soil fertility targets but the amounts declined to more stable inputs during the maintenance phase of the experiment (Fig. 2). An example of the overall success in achieving the target soil fertility levels is illustrated by the trend in soil fertility revealed by the annual January/February soil test monitoring points (e.g. Fig. 3 for the P2SR18 grazing system). The associated seasonal fluctuations in soil test values are shown by the open triangles on the graph. The net effect of the soil fertility management was to build soil fertility between 1994-2000 and for soil fertility management then to enter a maintenance phase (2001-2006). However, because of seasonal fluctuations in the extractable-P levels it was difficult to ensure that soil fertility remained constant during the maintenance phase and some drift in the Olsen-P levels occurred (Table 1). The P1* pasture was fertilised at P2 rates until 1998, before being allowed to return to the 10-12 mg P/kg range. This was achieved during 2001-2006, but soil fertility continued to decline gradually and the Olsen-P level of this treatment declined about 5 mg P/kg soil over the maintenance period. Grazing was disrupted by drought in 1994, but from 1995-2002 all pastures were grazed continuously with only moderate levels of feeding required in paddocks grazed at SR18 until the drought of 2002 when more extensive feeding was required. During the drought period from 2003-2006, pastures were grazed continuously whenever ground cover exceeded about 70% and were destocked at other times to reflect the recommended practice of feeding animals in a sacrifice area during drought.

Table 1. The farm-gate phosphorus balance of grazing systems managed at contrasting levels of soil P fertility: P0SR9 - unfertilised and grazed continuously by 9 yearling Merino wethers/ha; P1SR9 - optimal soil P fertility, grazed by 9 sheep/ha; P1SR18 - optimal soil P fertility, grazed by 18 sheep/ha; P2 SR9 - supra-optimal soil P fertility, grazed by 9 sheep/ha; and P2SR18 - supra-optimal soil P fertility, grazed by 9 sheep/ha.

	Soil fertility build-up phase (1994-2000)			Soil fertility maintenance phase (2001-2006)					
Grazing system	P input	P export	P accumulated in paddock	P input	P export	P accumulated in paddock	Change [2] in Olsen-P	Component [3] of P-input stored in soil fertility increase	Component of P accum. not associated with soil fertility increase
	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(mg/kg)	(kg/ha)	(kg/ha)

P0SR9	0.0	5.8	-5.8	7.8	4.5	3.2	0.5	1.7	1.5
P1SR9	145.6	7.5	138.2	52.6	6.7	45.8	1.7	5.5	40.3
P1SR18	145.9	12.9	133.0	70.3	11.4	58.9	3.6	11.6	47.4
P1*SR18	203.3	13.8	189.5	11.0	10.3	0.7	-5.6	-18.2	-17.5
P2SR9[1]	218.2	8.0	210.2	-	-	-	-	-	-
P2SR18	218.5	13.0	205.5	93.7	12.6	81.2	1.8	5.9	75.3
LSD (*P*=0.05)	0.8	1.3	1.7	5.4	2.6	12.6	2.4	-	20.1

[1] this treatment discontinued from 2003, [2] estimated by linear regression using Jan/Feb monitoring points, [3] estimated using the measured ratio of ΔOlsen P/kg P applied/ha = 3.2

P-balance of the grazing systems

Fertilised paddocks accumulated 89-93% of their P input (fertiliser+feed) over the whole experiment (1994-2006), whilst the P0 grazing system had a negative P-balance. However, the P-balance totals for the experiment as a whole included P that was contributing to changes in soil fertility as well as P accumulating in the paddocks in sparingly-available organic and inorganic soil pools. To gain an understanding of the efficiency of fertiliser use it was, therefore, more informative to examine the P-balance of the grazing systems during the soil fertility maintenance phase (2001-2006) where P-inputs were lower and more stable, and changes in soil fertility were relatively small. Allowance was made for the P stored in the small changes in plant-available P pools using the ratio of ΔOlsen P/kg P applied/ha that had been determined during the experiment for calculating the amounts of P-fertiliser to apply each year (Table 1).

If only P inputs and P export were considered, paddocks fertilised to the P1 level accumulated 46-59 kg P/ha during the maintenance phase (2001-2006). P2 paddocks accumulated 81 kg P/ha. However in every case, the soil fertility of these treatments increased marginally over this period. When this was taken into account, the accumulation of P in pools, not readily accessed by plants, was estimated to be 40-47 kg P/ha in P1 paddocks and 75 kg P/ha in P2 paddocks. Differences in the amount of P required to maintain the P1 fertility level when paddocks were grazed at SR18 compared with under-grazing at SR9 were not significant.

Total P input (215 kg P/ha) and the accumulation of P in paddocks (191 kg P/ha) did not differ between P1*SR18 and P1SR18 treatments over the whole experimental period (1994-2006). However, over the 2001-2006 period, soil fertility was improving marginally in the P1SR18 treatment and was declining in the P1*SR18 treatment.

Discussion

Grazing systems utilise fertiliser P less efficiently than many other agricultural enterprises (e.g. wool, meat milk and live animal enterprises: 20% of applied P exported in products cf. 45-54% for grain production; McLaughlin et al. 1992). Small amounts of P may be lost from paddocks in runoff and erosion (these losses can be minimised by management) and in sandy or highly fertilised soils by leaching. In most other soils, large amounts of phosphate accumulate as a result of continuing slow reactions between phosphate and soil particles, incorporation of P into organic materials that resist mineralisation and, in the case of grazed paddocks, through accumulations of excrement in stock camps. Barrow (1980a; 1980b) determined that the empirical relationship between net phosphate sorption by soil (Ps), P concentration in the soil solution (c) and time (t) for non-calcareous soils was of the form: $Ps = a.c^{b1}.t^{b2}$, where: *a* approximates the amount of sorbing material in a soil, and *b1* and *b2* are coefficients that describe the shape of the sorption relationship. These coefficients vary widely between soils, however, *b1* and *b2* are reasonably well correlated when compared across a wide range of soils (Barrow 1980a; 1980b) and from this it can be deduced that farming systems operated at higher soil P concentrations may promote faster continuing reactions between phosphate and soil particles and may lead to larger amounts of P sequestered into sparingly-available soil pools.

In the present experiment, the P-balance of grazing systems operated at three soil P concentrations (deficient, near-optimal, and supra-optimal), or by varying the soil P concentration, were examined to determine if the strategy used to manage soil fertility had a measurable impact on the efficiency with which P-fertiliser was used. The unfertilised pasture mined P from the soil except when P was being applied in the form of supplementary feed and was expected to be unsustainable over the longer term. Maintaining soil fertility at the P2 level (with SR18) required a higher P input, and more P was accumulated in P2 paddocks (+60% over maintenance at P1SR18). It was considered possible that differences in stocking rate may lead to differing amounts of P accumulated in camps and exported from paddocks in products. For this enterprise type (wool production), differences in P-export were small (<1 kg P/ha/year) and no significant difference in accumulation of P were detected once changes in soil fertility had been accounted for.

Adopting a varying fertiliser strategy (P1*SR18 treatment) in which soil P fertility was built rapidly and then exploited by withholding fertiliser was, on face value, not different to managing P at the near optimal soil fertility level (i.e. similar P applied and accumulated over the entire experimental period). However, over the final years of the trial, soil fertility improved marginally in P1SR18 paddocks and declined in P1*SR18 paddocks. When these changes in soil fertility were taken into account, it was clear that managing soil fertility to a consistent target was more effective and resulted in more efficient use of fertiliser P.

Conclusion

Managing paddocks at higher levels of soil P fertility than necessary for the production objectives of an enterprise is costly because more P is required to both build and maintain high levels of soil fertility.

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