Balancing phosphorus requirements for milk production and water quality

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Abstract

Phosphorus (P) is both an essential element for pasture and animal production and a limiting nutrient for nuisance weed and algal growth in many New Zealand water bodies. Research results, mainly measured under mowing, have shown that pasture production increased with fertiliser P application up to a target range of soil Olsen P values (20-30 mg/L for sedimentary and Allophanic soils; 35-45 mg/L for Pumice and Organic soils). A dairy farmlet trial in Taranaki on an Egmont Allophanic soil measured small increases in pasture production and larger economic responses in milksolids (MS) production as Olsen P levels increased from 30-50 in a management system with high stocking rates and a long lactation. The relative response in pasture production to Olsen P was similar under mowing and grazing, indicating that the MS response to high Olsen P measured on Allophanic soils would also apply to other soils.

Only small amounts of dissolved P (< 1 kg/ha) are required to promote nuisance weed and algal growth in water bodies. P can be sourced from soil, fertiliser and dung and transported in dissolved and particulate forms from soil to water through overland and subsurface runoff flow. Data from a P runoff study on different soils is presented which shows that the potential for P to be lost to water bodies increases with Olsen P level. On a high anion storage capacity (ASC) Egmont Allophanic soil (83%), the concentration of dissolved reactive P (DRP) in overland flow was lower than the critical level of 0.03 mg/L at Olsen P levels of 20-110 mg/L. In contrast, on the more weakly weathered Waikoikoi Pallic soil with low ASC (15%), the critical DRP level was exceeded at an Olsen P of about 30 mg/L, and on the moderately weathered Waikiwi Brown soil (ASC 49%), at an Olsen P of about 50 mg/L. These results indicate that there is a greater risk of P enrichment of surface water bodies in areas with low ASC than in areas with high ASC soils.

Keywords: allophanic soils, milksolids production, pasture, phosphorus loss, sedimentary soils, water bodies

Introduction

Phosphorus (P) is required for pasture growth on most New Zealand soils and is the most expensive nutrient applied (current cost $1.90/kg). During the last 50 years, there have been many trials measuring pasture production responses to P in New Zealand, nearly all under mowing. On average, these trials showed that near maximum pasture production was achieved at soil Olsen P levels in the range 20-30 mg/L for Allophanic and sedimentary soils (Brown, Pallic, Melanic and Semiarid soils) and 35-45 mg/L for Pumice and Organic soils (Roberts & Morton 1999). Because of the much greater cost of farmlet trials, there have only been three previous dairy grazing trials (two using Olsen P) measuring the response in milksolids (MS) production to applied P, all on an Egmont Allophanic soil in South Taranaki. In one of these trials (1990-1993), with an initial average soil Olsen P level of 20 mg/L and a stocking rate of 3.8 cows/ha, the most profitable response in MS production for the current fertiliser cost and MS price was obtained at 50 kg P/ha/yr which increased Olsen P to 45 mg/L at the end of the trial (Thomson *et al.* 1993). The results from another trial on the same site (1993-1996) with an initial average soil Olsen P of 33 mg/L and 4.0 cows/ha suggested that the economically optimum rate of P was within the range 25-100 kg P/ha/yr (Thomson 1995).

From these trial results, guidelines for dairy farmers were derived. If the farm was achieving average or below MS production/ha for the supply area, Olsen P levels were recommended to be maintained in the target ranges of 20-30 mg/L for Allophanic and sedimentary soils, and 35-45 mg/L for Pumice and Organic soils (Morton *et al.* 1997). It may be possible to achieve economic increases in MS production/ha above the target ranges if the farm is in the top 25% for the supply area or other inputs are increasing to achieve that level. This would require management to achieve high (> 80%) pasture utilisation (high stocking rate, conservation of most of the surplus pasture grown and long lactation) to produce high levels of MS/ha (Morton *et al.* 1997).

The reported 1996-2000 grazing trial was primarily carried out to establish that no significant differences in pasture production responses to Olsen P between mowing and grazing could be detected (Morton & Roberts 2001). This paper will describe the pasture and MS production results from that trial.

Many of New Zealand's water bodies have been found to be P-limited for nuisance weed and algal growths (eg. Crawford 2001). The intensification of agriculture has increased the risk of P loss from soil to water through overland and sub-surface flow of soil, fertiliser and dung P. The relationship between available soil P levels and P loss in runoff has been widely reported (e.g. McDowell & Sharpley 2001; Tunney *et al.* 2002) but there has been a lack of information on the effect of available soil P content of different New Zealand soil types on P loss. This paper will report on such work and relate it to agronomic and economic P requirements in dairy pasture systems.

Materials and methods

Grazing trial

The trial was conducted at the Westpac Taranaki Agricultural Research Station near Hawera in South Taranaki, New Zealand, from July 1996 to June 2000. The 25 ha site consisted of high fertility ryegrass dominant pasture, typical of the Taranaki region, grown on a well drained Egmont (Typic Orthic Allophanic) soil with a mean annual rainfall of 1100 mm.

The trial site had previously been part of a three-year rate of P x stocking rate farmlet trial (Thomson 1995) that had generated soil Olsen P levels, measured in March 1996, ranging from 20-89 mg /L. Fifty of these 60 paddocks at the site were selected and 10 allocated to each of 5 farmlets. The 5 farmlets, each consisting of 10 x 0.5 ha paddocks, had initial mean Olsen P levels, based on the average of the previous 3 years, of 29, 37, 45, 56, and 68 mg /L. No maintenance P fertiliser was applied during the 4-year trial duration to avoid any possible interaction in pasture response between Olsen P and freshly applied fertiliser P.

Soil cores (0-75 mm depth) sampled from each paddock in March 1997 had average soil quick test (QT) potassium 12.7, calcium 5.4, magnesium 37, sulphate sulphur (S) 43 mg /g and soil pH 5.7. To maintain the soil K and S levels, 175 kg potassium sulphate/ha /yr was applied in November to each paddock. Urea was also applied in two equal applications in spring to give a total of 120 kg N ha/yr.

Each farmlet was stocked with a separate group of Jersey/Friesan cows at 3.8 animals/ha. The paddocks were grazed at approximately 30-day intervals during spring and summer, extending to 50 days during autumn, and up to 120 days in winter when the cows were not lactating. In spring, when a farmlet group achieved a trigger post-grazing pasture mass above 1.7 t DM/ha, the paddocks with the highest pasture mass were conserved as silage.

Fifteen soil cores (0-75 mm depth) were sampled from each paddock and analysed using a modified half hour Olsen P test in March of each year. Pasture DM production was determined on each paddock by weekly visual assessment of pasture mass during the lactation and two-weekly during non-lactation. This assessment was corrected using calibration cuts from ten 0.1 m^2 quadrats of pasture trimmed to ground level, and a sub-sample dried for 12 hours at 90°C. Daily milk production was measured from each cow every 2 weeks during lactation and analysed for fat and protein to derive milksolids production.

P loss trial

Surface runoff losses of P were measured from 3 soils commonly used for dairying, including the Egmont soil used in the grazing trial reported here. Intact grassland soils (Waikiwi [Typic Firm Brown], Waikoikoi [Mottled Fragic Pallic], Egmont [Typic Orthic Allophanic]), of 7.5 cm depth were placed in 100 x 20 x 10 cm deep boxes and analysed for Olsen P that varied according to the fertiliser history of the paddocks from which they were taken. Anion storage capacity (ASC) was also measured on a bulked sample of each soil type that varied according to the presence of iron and aluminium oxides that retain P. Overland flow was generated by applying artificial rainfall at 1.5 cm/hr to boxes, inclined at 5% slope and within one to two weeks of collection. Samples of overland flow were taken for one hour after flow had been initiated, filtered (< 0.45 mm) and P determined via colorimetry in duplicate. Rainfall simulation and soil boxes used in this study accurately mimic the mechanisms controlling the release of P to saturation-excess overland flow in the field (McDowell & Sharpley 2002). However they are not designed to quantify P losses on the field scale *per se.*

Results

Grazing trial

The response in pasture production to increasing Olsen P was small, averaging 700 kg DM/ha/yr, as Olsen P increased from 22 to 50 mg/L (Figure 1). There was considerable variation in the slope of fitted lines between years; positive in two of the years, constant and negative in each of the other years (Morton & Roberts 2001).

The increase in Olsen P from 22 to 50 mg/L resulted in an average response of 112 kg MS production/ha/yr (Figure 2). The response in MS/ha

Figure 1 Relationship between soil Olsen P and annual pasture production – mean of 4 years.

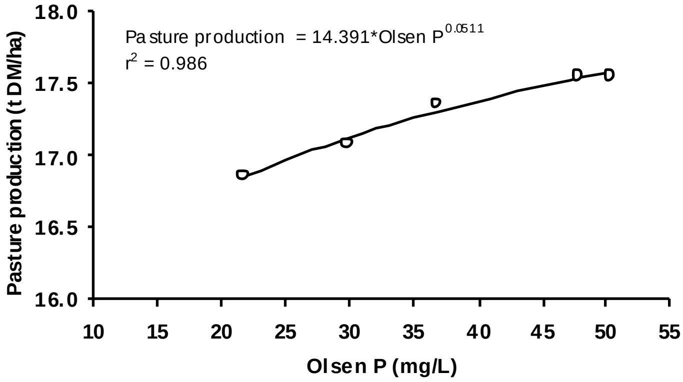


Figure 2 Relationship between soil Olsen P and MS production/ha/yr – mean of 4 years.

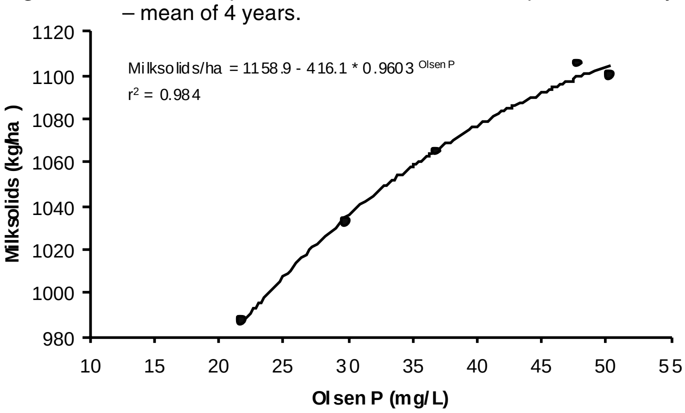
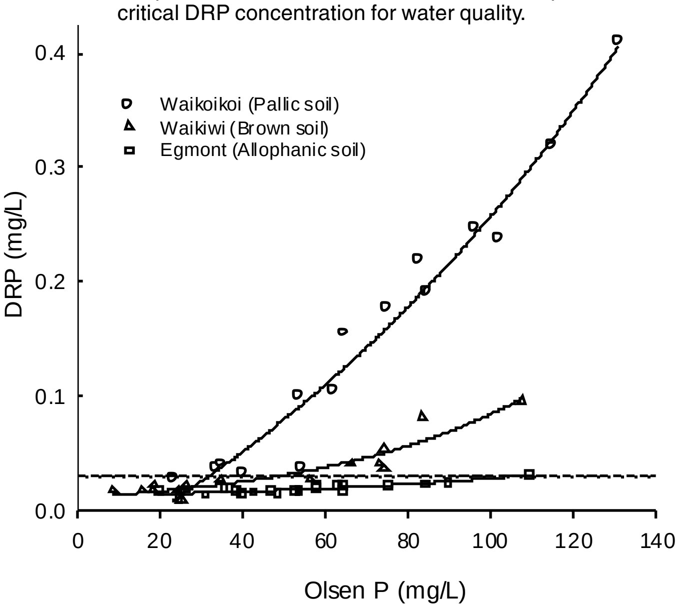


Figure 3 Relationship between soil Olsen P levels and DRP concentration in surface runoff from Pallic, Brown and Allophanic soils. Dashed horizontal line represents the critical DRP concentration for water quality.



tended to be linear up to an average Olsen P of 41 mg/L in Year 1, 50 mg/L in Year 2, 53 mg/L in Year 3 and 43 mg/L in Year 4 (results not shown).

P loss trial

For the weakly weathered Waikoikoi Pallic soil with a low ASC of 15%, DRP concentration in overland flow exceeded surface water quality guidelines (0.03 mg/L) at an Olsen P level near 30 mg/L (Figure 3). In contrast, for the Egmont Allophanic soil with a high ASC of 83%, the DRP concentration guideline was only exceeded at very high Olsen P levels (>110 mg/L). The moderately weathered Waikiwi Brown soil (ASC 49%) was intermediate between those of the Waikoikoi Pallic and Egmont Allophanic soils, with DRP concentrations exceeding the guideline at Olsen P levels greater than 50 mg/L.

Discussion

Since the grazing trial was carried out at relatively high Olsen P levels, typical of New Zealand dairy soils, the slope of the pasture production response curve was relatively flat, similar to the upper part of the average response curve for Allophanic soils (Roberts & Morton 1999). The response in MS production/ha at high Olsen P levels was greater than would have been expected from the measured increase in pasture production. Higher Olsen P resulted in greater pasture growth rate for certain periods during lactation that varied between years and these small increases were able to be directly utilised for milk production at the high stocking rate used or conserved as silage. In spring, pasture surpluses were recognised early and conserved as silage to be fed in late lactation. More silage was conserved on the high Olsen P farmlets which allowed an average increase in lactation length of 14 days for the highest (246 days) compared to the lowest (232 days) Olsen P farmlet herd. Alternatively, differences in pasture production between farmlets, which have potentially higher errors in measurement than MS production, may have been underestimated. Nevertheless, it is likely that to achieve similar increases in MS production (average of 66 kg/ha/yr) to pasture production responses at Olsen P levels greater than the target range (20-30 mg/L), a similar management system to the one used in this trial would need to be employed. The trial system achieved high pasture utilisation (90% using 15 kg DM consumed/kg MS) through a high stocking rate coupled with modest average per cow production (277 kg MS), conservation of a large proportion of the spring pasture surplus and maximising lactation length. A lower stocking rate combined with higher per cow production could achieve the same MS production/ha but early recognition of pasture surpluses would be more critical.

A simple marginal economic analysis can be carried out from the grazing trial results. Increasing Olsen P from 30 (the upper end of the target range) to 50 mg/L resulted in an extra 60 kg MS/ha which at the current price of \$3.60/kg MS gained \$216/ha per year extra revenue. If the extra 500 kg DM/ha grown was utilised at 90%, then at the average 277 kg MS/cow produced and using 15 kg DM consumed per kg MS, an extra 0.15 cows/ha would be required to convert the extra pasture production to milk. For estimated cow operating variable costs including labour of \$1500/ha, pasture conservation \$180/ha, maintenance fertiliser \$55/ha, N fertiliser \$91/ha, cow replacement costs \$390/ha,10% interest on capital P fertiliser \$22/ha and on cow purchase \$90/ha, the total cost for the extra cows was \$2328 ha. For the extra 0.15 cows/ha this would equate to \$349/ha to give a payback period for increasing Olsen P and implementing the management changes of 1.6 years.

It is of interest to compare the relationship between relative pasture yield and Olsen P from this grazing trial compared to the average response curve derived from national mowing trials (Roberts & Morton 1999). At soil Olsen P 22, the relative yield (% of maximum yield) from the reported grazing trial was 96% compared with 97% from the mowing trials. The average relationship from the mowing trials is used in the OVERSEER® Nutrient Decision Support Programme to model economically optimal fertiliser P requirements on dairy farms. Using inputs from the grazing trial, the model predicts that it would be 6 years before the costs of increasing Olsen P from 30 to 38 mg/L are recovered from extra milk production compared with the 1-2 year payback period from increasing Olsen P from 30 to 50 mg/L calculated earlier. The better economic return from the grazing trial was probably caused by the higher than expected MS response to the increase in pasture production. It should also be noted that there was considerable variation in relative pasture production at a specific Olsen P level between mowing trial sites for all soil groups (Roberts & Morton 1999).This variability indicates that an economic response in MS production may not always be achieved from increasing Olsen P above the target range on all dairy farms.

Guidelines for Olsen P levels on dairy farms that feed mainly pasture to the herd have been developed by indexing MS production/ha on an individual farm to that for the milk supply area rather than a national universal value because of variation in soils and climate (Morton *et al.* 1997). For average MS/ha, the target Olsen P range is 20-30 mg/L on sedimentary and Allophanic soils and 35-45 mg/L on Pumice and Organic soils. In an Irish study, at a stocking rate of 2.6 cows/ha, which is close to the average for New Zealand dairy farms, Culleton *et al.* (1998) reported no significant increase in milk production above Olsen P levels of 20 mg/L on a sedimentary soil. If MS/ha is in the upper 25% for the supply area, or it is intended to increase to this range, economic responses may be able to be achieved at Olsen P levels above these target ranges. The choice of the upper 25% range is mainly based on data from a survey of South Taranaki dairy farms (Howse & Leslie 1997), where the top 25% of farms surveyed had MS production/ha and Olsen P at a similar level as on the grazing trial for that year.

Because all of the 3 dairy grazing trials measuring MS responses to Olsen P have been carried out on Allophanic soils, it is important to establish that the results will also apply to other major soil groups. Results from several New Zealand mowing trials show a similar relationship between Olsen P and relative pasture production for Allophanic and sedimentary soils (Roberts & Morton 1999). The lower volumetrically derived Olsen P levels for Allophanic and sedimentary soils compared with Pumice and Organic soils, at the same level of pasture production, are due to their higher bulk density. No detected difference in pasture production response to increasing Olsen P was measured under mowing and dairy grazing on an Allophanic Egmont soil (Morton & Roberts 2001). Therefore this would indicate that the target ranges for Olsen P that have been mainly derived from mowing trials, are applicable to dairy grazing and milk production on all soil types.

The P runoff results suggested that the risk of higher Olsen P increasing dissolved P loss from soil to water was dependant on the ASC of the soil, in addition to other factors such as rainfall patterns, topography and fertiliser management. There is a much higher risk of P loss in overland flow on low ASC Pallic and Recent soils than on high ASC Allophanic soils, if Olsen P is above the target range of 20-30 mg/L. Higher Olsen P levels will also contribute to increases in P loss from other sources such as P bound to soil particles and contained in dung. Therefore on dairy farms, where these soils are in the vicinity of sensitive, P-limited water bodies, soil Olsen P levels should ideally not be increased above the target range. In this situation, other best management practices to minimise P loss in runoff should also be in place. These include allowing a margin of greater than 10 metres between the P fertilised area and open water, excluding stock from all water bodies to prevent P entering water directly from dung or via stream bank erosion, no application of P to saturated soils or before heavy rainfall, and fencing off a riparian strip on each side of all swamps, drains, streams and rivers. To minimise the loss of P, these practices should be used on all farms, regardless of soil type.

Conclusions

If an increase in pasture production from increasing Olsen P does occur, a response in animal production and hence greater economic returns from high Olsen P levels will not be achieved unless an animal management system is put in place to utilise the sometimes small extra amount of feed that could be provided. An increase in Olsen P above the target ranges without the more difficult corresponding changes in management could result in a financial loss from the use of higher fertiliser P inputs. It will also have the potential to increase losses of P from the soil to water bodies and enhance nuisance weed and algal growths. The risk of P loss from dairy farms with high Olsen P levels will increase as soil ASC decreases.

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