A RECONSIDERATION OF THE TARGET OLSEN P RANGES FOR DAIRY FARMS

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Introduction

The current recommended target ranges for Olsen P on dairy farms are 20-30 or 30-40, depending on pasture production relative to the district average (Roberts and Morton 2009). These target ranges were based in part on P response curves derived from a large database of historical P response trials. These response curves were first presented in Roberts and Morton (1999) and have been reproduced, essentially unaltered, in subsequent publications (e.g. Roberts and Morton 2009). From these response curves, the critical Olsen P values required to achieve a relative yield of 97% were estimated to be 20 and 22 for sedimentary and volcanic soils respectively (Mackay et al., 2010).

Edmeades et al. (2006) re-analysed data from the same database of P response trials and derived critical Olsen P levels required to achieve 97% of maximum production of 32, 30 and 25 for volcanic, sedimentary and recent soils. These values are somewhat higher than those reported in Roberts and Morton (1999). Edmeades et al. (2006) attributed these differences in critical P levels to the application of “more rigorous protocols” when selecting the dataset used in their analysis.

More recently, Mackay et al. (2010) investigated the P response at 7 pasture sites in the absence and presence of added N (400 kg N/ha/yr). The critical Olsen P values corresponding to 97% of maximum production were estimated to be 43 and 37 for the 0N and 400N treatments respectively, with the authors noting that the critical value (43) in the absence of added N may be underestimated. These critical P values were again higher than those estimated by Roberts and Morton (1999) and this led Mackay et al. (2010) to suggest that perhaps the current target Olsen P values should be reassessed.

Although Roberts and Morton (1999), Edmeades et al. (2006) and Mackay et al. (2010) derived different critical Olsen P values corresponding to 97% of maximum production, all three studies recognised that there was considerable variability in the data, and hence some uncertainty in the estimated critical values. Inspection of some of the data presented by Edmeades et al. (2006) (Table 1) suggests that confidence intervals ($P < 0.05$) of approximately ±4 in the critical Olsen P value may be typical. This is after much of the variation due to differences in soil group has already been removed by considering data from the major soil groups separately. Although some of this variation can be attributed to random variation in trial measurements, there are also likely to be systematic differences in critical Olsen P values between sites.

Table 1 Estimated relative pasture production at Olsen P (0-75 mm, µg P cm^{-3} dried and sieved soil) levels of 25 and 50 and critical level required to acieve 97% maximum production, for the major soil groups in New Zealand (numbers in brackets are the confidence intervals ($P < 0.05$)). (Data from Edmeades et al. (2006))

Soil group	Relative pasture production		Critical level
	Olsen P 25	Olsen P 50	
Volcanic	92 (88-94)	99 (98-100)	32 (27-38)
Sedimentary	95 (93-97)	100	30 (26-32)
Recent Soils	97 (96-98)	99 (98-100)	25 (20-30)

There are many factors that could cause this. One of these is the actual level of pasture production - which is masked when expressing pasture production in terms of relative yield. When analysing data from the RPR National Series, Sinclair et al. (1997) found that sites with high annual pasture production tended to have higher critical Olsen P levels than sites with low annual pasture production.

There are a number of physical and biological reasons why the critical Olsen P value might depend on annual yield. Phosphorus moves to plant roots by diffusion through the soil solution. The rate of diffusion is determined, in part, by the P concentration gradient in the soil solution between the root surface and the surface of the soil particles. High rates of pasture production require high rates of P diffusion and therefore a high concentration of P on the soil surface (and hence a high Olsen P test value) would be an advantage. Other factors that affect the rate of P diffusion to plant roots soil moisture content and the root density. Thus, if root density is restricted for some reason (e.g. soil compaction) then a higher Olsen P value may be required to ensure that P can diffuse sufficiently quickly to the more widely separated roots. Mackay et al. (2010) presented some evidence to support a higher critical Olsen P value in compacted soils.

However, although there are good physical and biological reasons to suggest that critical Olsen P values corresponding to 97% of maximum pasture production will vary in a non-random way between sites, it is not possible at this stage to predict with confidence whether the critical Olsen P value at a given site will be above or below the average value determined from the whole dataset. And even if it was possible to determine a precise relationship between Olsen P and relative yield at a site, the measured Olsen P value itself is subject to significant spatial and temporal variability.

Given this currently uncontrollable variation, the approach of Roberts and Morton (2009) of presenting target Olsen P ranges, rather than specific critical values corresponding to 97% of maximum pasture production is sensible - although there is still the matter of what these target ranges should be.

Even if the relationship between Olsen P and pasture production is known exactly, there are still many other factors that affect the financially optimum Olsen P value for individual farmers. These include the P fertiliser price, the milk solid (MS) payout, the ability of the farmer to convert extra pasture grown to MS, and any additional costs that may be associated with the higher levels of production. The uncertainty associated with the Olsen P test and its calibration is just another factor to consider.

When faced with this degree of uncertainty as to the optimum level of soil fertility, it is helpful to consider the likely financial costs and benefits of a decision to increase the current Olsen P level on a farm. This paper reports on a modeling study that investigates the sensitivity of the financially optimum Olsen P test on dairy farms on sedimentary and volcanic soils in New Zealand.

Methods

Response curves generated using a simple geometric progression were fitted by eye to the data of Edmeades et al. (2006) for sedimentary and volcanic soils (Table 1). Three response curves were generated for each soil group representing the average value and the extremes of the confidence intervals ($P < 0.05$) for the critical values corresponding to a relative yield of 97% and the relative yields at Olsen P values of 25 and 59 (Table 1). The response curves fitted to the average values for the critical Olsen P value and the relative yields at Olsen P values of 25 and 50 for both sedimentary and volcanic soils are presented in Figure 1 to demonstrate their overall shape. In the remainder of the paper however, the main focus will be on the regions of the response curves between Olsen P values of 25 and 50 (Figure 2), as in these regions the curves fit closely the data of Edmeades et al. (2006) that are derived from the large database of historical trials. The three curves spanning the confidence intervals for volcanic soils are presented in Figure 3. Similar response curves were generated for sedimentary soils. The data from these response curves were then used in a net present value (NPV) analysis to determine the financially optimum Olsen P value for a range of scenarios.

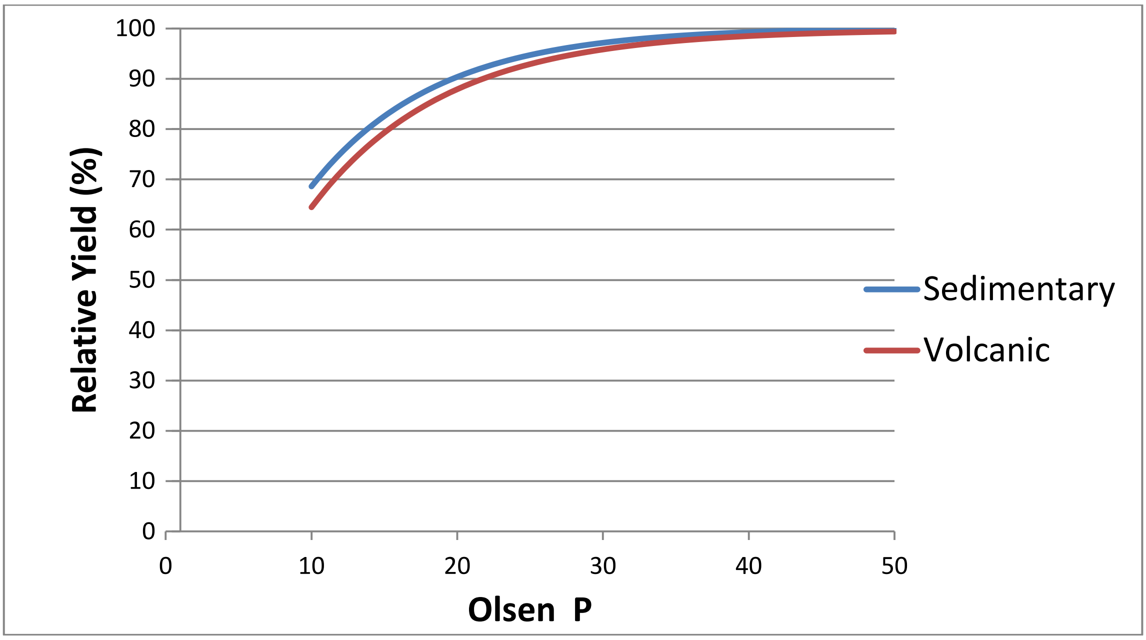

Figure 1. Relationships between relative pasture yield and Olsen P for sedimentary and volcanic soils. Curves estimated from data presented by Edmeades et al. (2006)

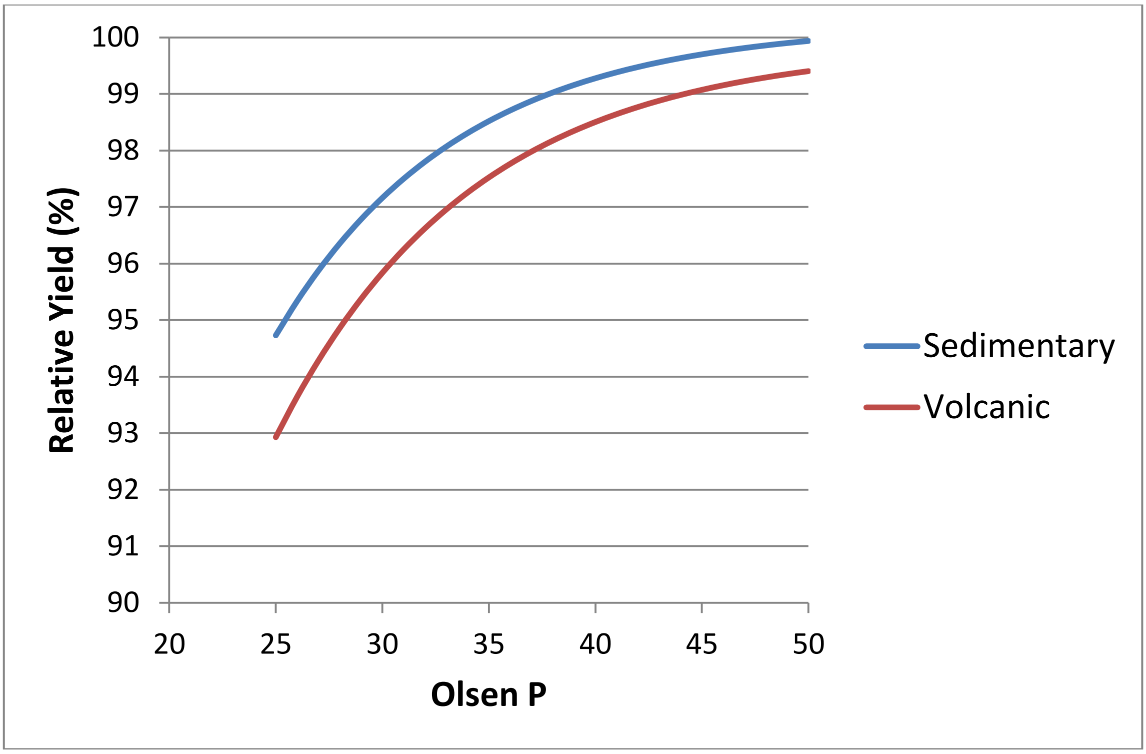

Figure 2. Relationships between relative pasture yield and Olsen P for Olsen P values ≥25 for sedimentary and volcanic soils. Curves estimated from data presented by Edmeades et al. (2006).

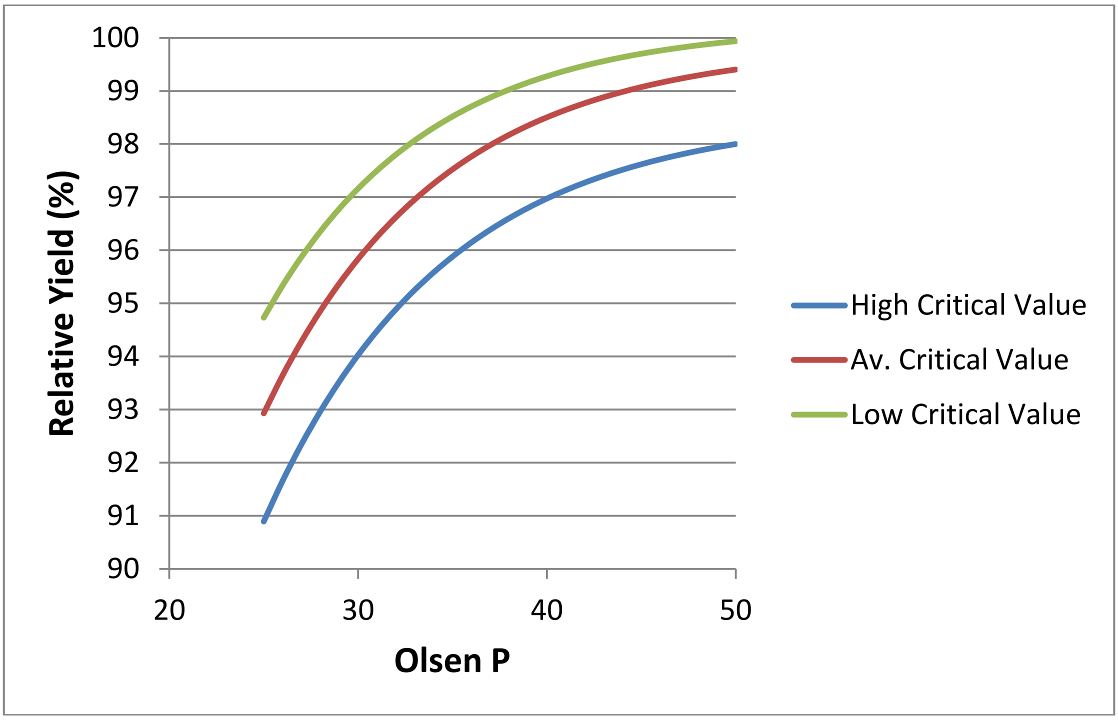

Figure 3. Relationships between relative pasture yield and Olsen P on volcanic soils**.** The three curves span the confidence interval ($P < 0.05$) of critical Olsen P values corresponding to 97% pasture yield reported by Edmeades et al. (2006)

Base Scenario

As a first step, a base scenario was established that was “representative” of a “typical” dairy farm (Table 2). This farm was assumed to have a potential annual pasture production of 13,000 kg DM ha^{-1} and the utilization of additional DM produced as a result of increasing the Olsen P level was assumed to be 80%. The efficiency of conversion of extra DM ingested to extra milk solids (MS) produced will vary between farms depending largely on whether the additional DM is eaten by existing cows that were previously underfed or by additional cows. For the same reason, the value of the extra MS produced, after subtracting any additional costs (other than fertilizer which is accounted for separately) associated with the increase in production, will vary considerably between farms. In the base scenario the ratio of additional DM ingested to additional MS produced was assumed to 15:1 and the net value of the additional MS produced was assumed to be \$5 kg^{-1} MS.

Increasing and then maintaining a higher Olsen P level in soil requires expenditure on capital fertilizer to lift the Olsen P level and then increased maintenance fertilizer to maintain the higher Olsen P level. The quantity of fertilizer P (above maintenance) required to increase the Olsen P level by 1 unit is termed the P buffering capacity. In this study the P buffering capacities of sedimentary and volcanic soils were assumed to 8 and 12 kg P per unit increase in Olsen P in sedimentary and volcanic soils respectively (Edmeades et al. 2006). The annual increase in maintenance fertilizer P required to maintain an increase in Olsen P of 1 unit was assumed to be 0.4 kg P ha^{-1} and 0.8 kg P ha^{-1}. The on-ground cost of P fertilizer was assumed to be \$5 kg^{-1} P.

Table 2. A base scenario of “representative” dairy farms on sedimentary and volcanic soils

	Sedimentary Soils	Volcanic Soils
Potential pasture production (kg DM ha^{-1})	13,000	13,000
Utilisation of additional pasture (%)	80	80
Conversion of DM to MS (kg kg^{-1})	15	15
Marginal MS payout (\$ kg^{-1} MS)	5.00	5.00
Soil P buffering capacity (kg P ha^{-1}.unit^{-1} Olsen P)	8	12
Additional maintenance P (kg P ha^{-1}.unit^{-1} Olsen P)	0.4	0.8
On-ground cost of fertilizer P (\$ kg^{-1} P)	5	5
NPV discount rate (%)	10	10
NPV term (y)	5	5

Effect of variability in P response curves and Olsen P values on the optimum Olsen P

Once the base scenario was established, the financially optimum Olsen P value was assessed for each of the 6 response curves described above. The implications of uncertainty in the measured Olsen P values to decisions about the financially optimum Olsen P value were also assessed.

Sensitivity of the optimum Olsen P value to potential DM production and MS payout

The sensitivity of the financially optimum Olsen P value to changes in MS payout and potential pasture production was assessed for the “average” response curves on both sedimentary and volcanic soils. Finally the effect of a possible link between critical Olsen P value and potential pasture production, as suggested by Sinclair et al. (1997), on the finically optimum Olsen P value was explored.

Results

Base scenario

The results of the NPV analyses for the base scenario are presented in Figures 4 and 5. Figure 4 presents the NPV (assessed over 5 years) of a decision to increase the Olsen P by 1 unit from its initial value. The Olsen P value at which the NPV is close to zero is taken to be the financially optimum Olsen P value. For the base scenario the financially optimum Olsen P values for the sedimentary and volcanic soils were 30 and 28 respectively (Figure 3 and Table 1). Although the volcanic soil has a higher critical Olsen P value (corresponding to 97% relative yield, Table 1) the financially optimum Olsen P value is predicted to be slightly lower. This is because the higher buffering capacity of the volcanic soil requires greater amounts of fertilizer P to increase and then maintain the Olsen P level.

The further the initial Olsen P value is below the financially optimum Olsen P value, the greater the NPV of a decision to increase the Olsen P value by 1 unit (Figure 4). In the base scenario a decision to increase the Olsen P from 25 to 26 has a NPV (over 5 years) of approximately \$38 ha^{-1} and \$27 ha^{-1} on a sedimentary and volcanic soil respectively (Figure 4). It would be expected that these NPVs would increase rapidly at Olsen P values <25, as indicated qualitatively in Figure 4, but quantifying this would require extrapolation of the relative yield response curves beyond the data set used to create them and so this is not done here.

Increasing Olsen P values by 1 unit when the initial Olsen P value is above the financially optimum results in a negative NPV. As the initial Olsen P levels increase, the NPVs of the decision to increase Olsen P by 1 unit approach limits of approximately -\$39 ha^{-1} and -\$62 ha^{-1} on sedimentary and volcanic soils respectively. These negative limits are the cost of the fertiliser required to increase the Olsen P value by 1 unit and then to maintain it at this higher level.

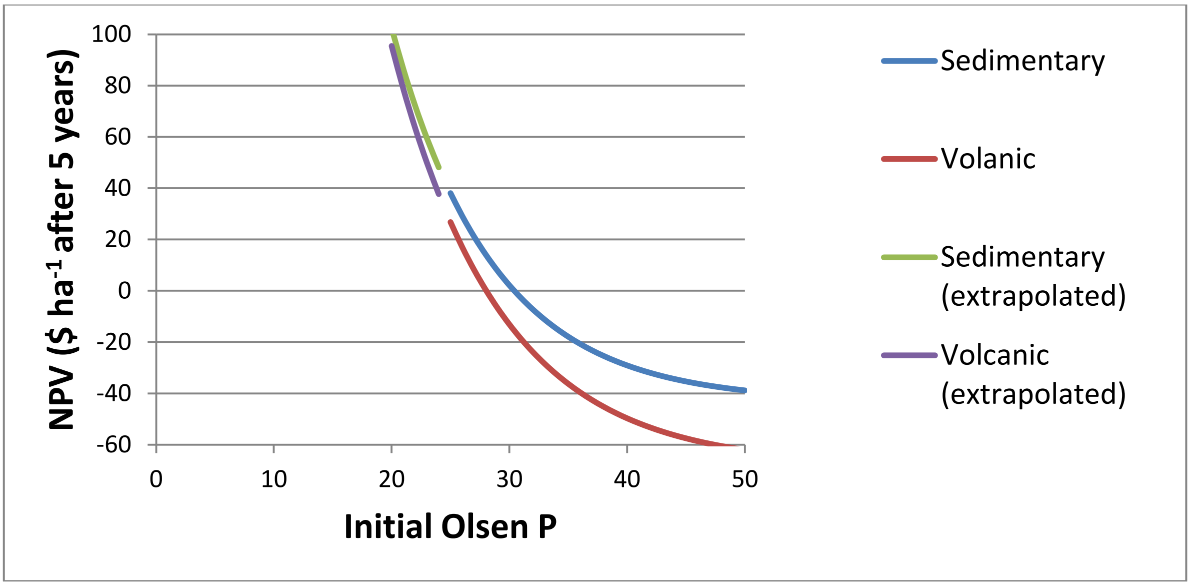

Figure 4. Calculated NPV (\$ ha^{-1} after 5 years) of a decision to apply fertilizer to increase Olsen P by 1 unit from initial Olsen P values >25 and estimated NPV (\$ ha^{-1} after 5 years) of a decision increase Olsen P by 1 unit from initial Olsen P values between 20 and 24.

Although it is interesting to see the NPV per unit increase of Olsen P, most farmers are likely to be more interested in the financial benefit from increasing Olsen P from the current value to the financially optimum value, or the financial loss resulting from a decision to increase the Olsen P from the financially optimum value to a higher value and then maintain the soil at this higher level (Figure 5). Maintaining an Olsen P level 4 units below the financial optimum results in an opportunity cost over 5 years of approximately \$74 ha^{-1} and \$90 ha^{-1} on sedimentary and volcanic soils respectively. In contrast, a decision to increase the Olsen P level 4 units above the financially optimum level has an NPV after 5 years of -\$36 ha^{-1} and -\$63 ha^{-1} on sedimentary and volcanic soils respectively. The data in Figure 5 focus on Olsen P levels ±4 from the financially optimum Olsen P level. It has been observed however (e.g. Wheeler 2004), that many dairy farmers have Olsen P levels very much greater than the financially optimum Olsen P levels identified above. It is interesting to note that a decision to increase the level of Olsen P to 50 on a volcanic soil would have an NPV over 5 years of approximately -\$960 ha^{-1}.

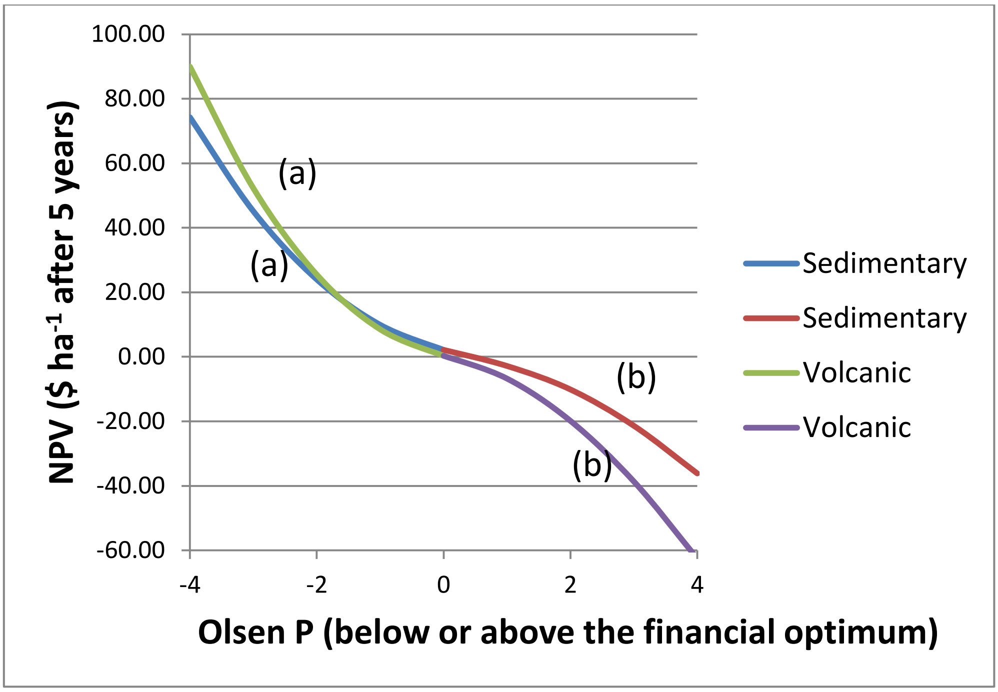

Figure 5. NPV (\$ ha^{-1} after 5 years) of a decision to (a) increase the Olsen P value by the amount needed to reach the financial optimum or (b) increase the Olen P test above the financial optimum on sedimentary and volcanic soils.

Effect of variability in P response curves and Olen P values on the optimum Olsen P

The NPV calculations illustrated in Figures 4 and 5 were calculated from response curves based on the average relative yield data for sedimentary and volcanic soils in Edmeades et al. (2006). If instead, the response curves were based on the upper and lower bounds of the confidence interval ($P < 0.05$) reported by Edmeades et al. (2006) the financially optimum Olsen P level changes slightly (Table 3).

The greatest change from the optimum Olsen P level calculated from the average response curves is on volcanic soils and amounts to 2 Olsen P units (Table 3). Thus for the base scenario on volcanic soils there is a slight chance that the financially optimum Olsen P value is 26, not 28. If such a farmer was advised to increase the Olsen P test to 28, this would impose an unnecessary cost. However, the cost is not large. The NPV over 5 years of increasing the Olsen P value from the optimum to two units higher is approximately \$20 ha^{-1} (or \$4 $ha^{-1}.y^{-1}$) (Figure 5).

Similarly, for the base scenario on sedimentary soils, there is a small chance that the financially optimum Olsen P value is 31, not 30 (Table 3). In this case, if a decision not to increase the Olsen P from 30 to 31 would have an opportunity cost due to lost profitable production. Once again, the cost would be small (approximately \$10 ha^{-1} over 5 years).

However, although small, the opportunity costs of not increasing the Olsen P value to the financial optimum are slightly greater than the unnecessary costs of increasing the Olsen P by an equivalent amount above the financial optimum (Figures 4 and 5). This raises the question of whether it would be worthwhile to deliberately raise the Olsen P above the apparent financial optimum to avoid a possible greater loss if the optimum Olsen P is higher than the average.

Table 3. Financially optimum Olsen P values for sedimentary and volcanic soils calculated from response curves that span the confidence interval ($P < 0.05$) of critical Olsen P values reported by Edmeades et al. (2006).

Form of relative response curve	Financially optimum Olsen P value	
	Sedimentary soils	Volcanic soils
High critical Olsen P value	31	28
Average critical Olsen P value	30	28
Low critical Olsen P value	29	26

Assuming a confidence interval ($P < 0.05$) of ±1 Olsen P unit around the optimum Olsen P (Table 3), adopting this strategy on volcanic soils would result in about 25% of farmers having a positive NPV of about \$8 ha^{-1} and the remaining 75% of farmers having negative NPVs between -\$7 ha^{-1} and -\$13 ha^{-1}. We would therefore conclude that if, as is currently the case, the position of a response curve within the confidence interval reported by Edmeades et al. (2006) is random, or at least unknown, then the best financial outcome will probably be achieved if the average response curve is assumed to be the correct one.

Of potentially greater interest is the uncertainty associated with the Olsen P test itself. This uncertainty is likely to be greater than that associated with the relative yield response curves (Table 3), to the extent that it may be thought prudent to aim for a soil test slightly higher than the financial optimum to guard against a possible large opportunity cost if the actual Olsen P is lower than the measured value. If in the base scenario on a volcanic soil, the confidence interval ($P < 0.05$) about an Olsen P test of 25 was ±4 units, increasing the Olsen P by 1 unit above the financial optimum would result in about 40% of farmers having positive NPVs between \$8 ha^{-1} and \$38 ha^{-1}. The remaining 60% of farmers would have negative NPVs between -\$7 ha^{-1} and -\$28 ha^{-1}. The weighted average NPV over 5 years of a large group of such farmers would be slightly negative - approximately -\$3 ha^{-1}.

On sedimentary soils in the same situation, approximately 40 % of farmers would have positive NPVs between \$8 ha^{-1} and \$38 ha^{-1}, and the remaining 60% of farmers would have negative NPVs between \$3 ha^{-1} and \$18 ha^{-1}. The weighted average NPV over a large group of such farmers would be close to zero.

Sensitivity of the optimum Olsen P value to potential DM production and MS payout

As the potential production increases, the financially optimum Olsen P value also increases (Figure 6). At a potential pasture production of 9,000 kg DM ha^{-1} the optimum Olsen P values are 27 and 24 for sedimentary and volcanic soils respectively. At a potential pasture production of 18,000 kg DM ha^{-1} the optimum Olsen P values are 33 and 31 on sedimentary and volcanic soils respectively.

This analysis of the sensitivity of the optimum Olsen P value to potential production was based on the average response curves for sedimentary and volcanic soils as reported by Edmeades et al. (2006). If however, the suggestion by Sinclair et al. (1997) that critical values increase with potential yield is correct, then in situations when the potential is high it may be more appropriate to use response curves with critical values near the upper bound of the confidence interval ($P < 0.05$) reported by Edmeades et al. (2006). If this is done the optimum Olsen P values when the potential yield is 18,000 kg DM ha^{-1} increase to 37 and 35 on sedimentary and volcanic soils respectively.

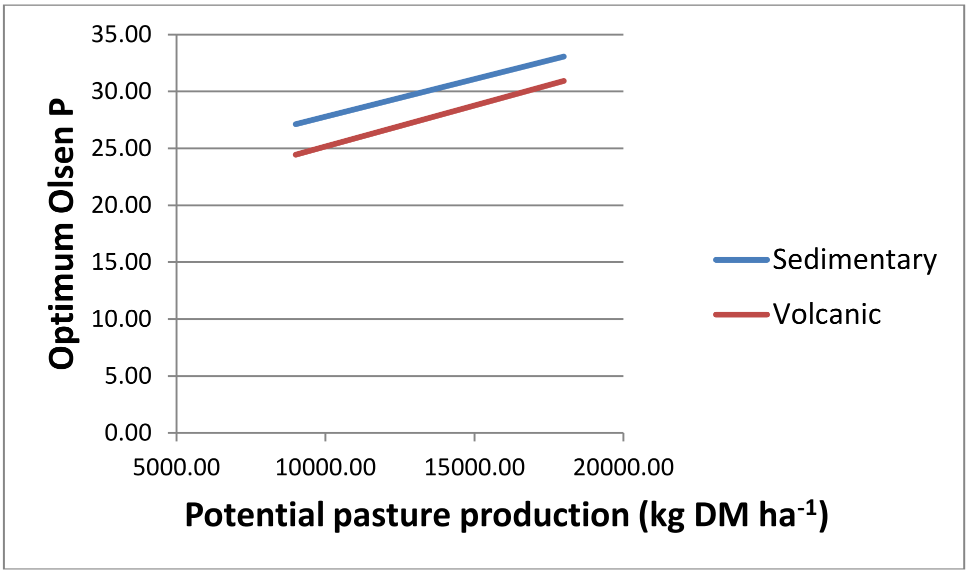

Figure 6. Relationship between potential pasture production (kg DM ha^{-1}) and the financially optimum Olsen P value on sedimentary and volcanic soils.

In a similar way the optimum Olsen P value increases with increasing marginal MS payout (Figure 7). As the marginal payout increases form \$3 kg^{-1} MS to \$8 kg^{-1} MS the optimum Olsen P value increases from 26 to 34 on sedimentary soils and from 23 to 34 on volcanic soils.

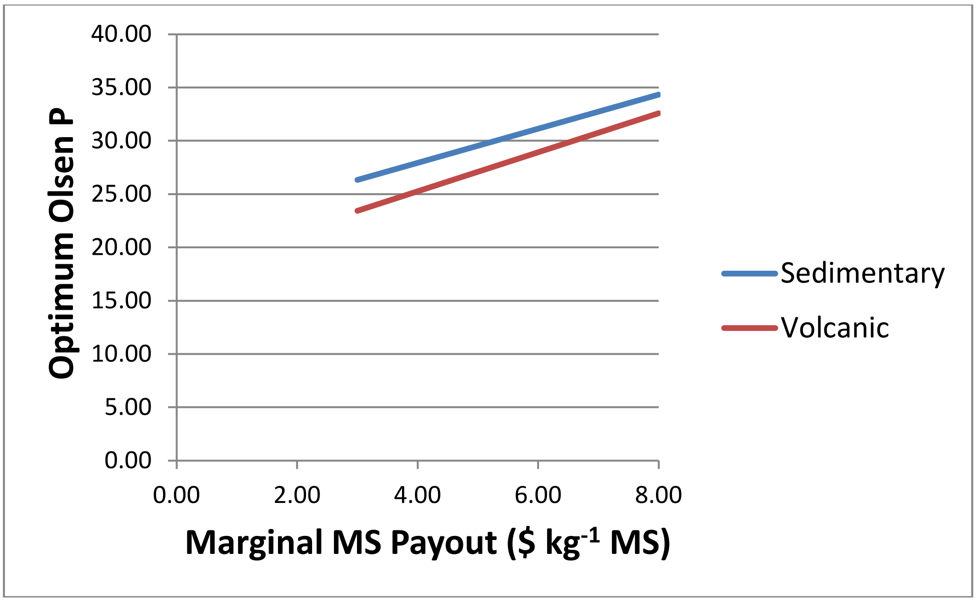

Figure 7. Relationship between the marginal payout ($ kg^{-1} MS) on extra MS produced (i.e. payout less additional non-fertiliser costs associated with producing the extra MS) and the optimum Olsen P value on sedimentary and volcanic soils.

Finally, if these factors are all combined so that a high potential pasture production (18,000 kg DM ha^{-1}) is associated with a response curve generated assuming a higher critical Olsen P value (Edmeades et al. 2006), a high marginal MS payout ($7.00 kg^{-1} MS) and a more efficient conversion of ingested DM to MS (13 kg DM : 1 kg MS) the financially optimum Olsen P values increase to 39 and 36 for sedimentary and volcanic soils respectively.

Discussion and Recommendation

The current target ranges for Olsen P on sedimentary and volcanic soils of 20-30 for most dairy farms, and 30-40 on high producing farms (Roberts and Morton, 2009), would be reasonable if the critical Olsen P values of 20 and 22 estimated by Roberts and Morton (1999) for sedimentary and volcanic soils respectively were indeed correct. If however, the critical Olsen P values corresponding to 97% of maximum pasture production are somewhat higher than 20 and 22 – as suggested by Edmeades et al. (2006) and Mackay et al. (2010) – then the bottom end of the current range may be too low. The NPV analyses reported in this paper indicate that in most dairy farming situations a profitable response to increased Olsen values will occur at Olsen test values <25. We therefore recommend that the lower threshold of the target range be raised from 20 to 25 for dairy farms on both volcanic and sedimentary soils.

The NPV analyses reported in this paper also support the recommendation of Roberts and Morton (2009) that the same target Olsen P ranges should apply to sedimentary and volcanic soils. Although both Roberts and Morton (2009) and Edmeades et al. (2006) reported slightly higher critical Olsen P levels (corresponding to 97% relative yield) on volcanic soils than sedimentary soils, the NPV analyses reported here suggest that the financially optimum Olsen P value may be slightly higher on sedimentary soils. This is because of the greater expenditure on P fertilizer required on volcanic soils to increase the Olsen P test value. The differences between soil groups however are small and many other on-farm factors will also influence the optimum Olsen P value. It therefore seems sensible to have the same target range for these two soil groups.

The effect of raising the lower threshold from 20 to 25 on actual fertiliser use on dairy farms is likely to be small. Most dairy farms already have Olsen P levels considerably above 25 (e.g. Wheeler, 2004) and increasing the lower threshold to this level will have little or no effect on the average Olsen P levels on New Zealand dairy farms. It may however, make the recommendation scheme more credible to those farmers and consultants who are currently choosing to maintain Olsen P values considerably above the recommended target ranges.

At higher levels of Olsen P the farmer's management skills in converting any extra pasture grown into MS become very important in determining whether applying the extra P is profitable. This is recognised in the current two-tier target range, with only the highest producing farmers being recommended to have an Olsen test above 30. However, reducing the size of the target range from 20 (20-40) to 15 (25-40) provides an opportunity to eliminate the formal division between the two "sub-ranges". As demonstrated here, there is already some uncertainty around the most appropriate values for the lower and upper thresholds, and the dividing point between the two ranges is even "fuzzier". We therefore recommend that there be only one target Olsen P range of 25-40 for dairy farms on sedimentary and volcanic soils, and that an explanatory note be developed to assist farmers and consultants decide where in this target range would be most appropriate for their farm. One consideration would be the level of production – as at present. But in the future there may be others. These could include the use of irrigation, the extent of N fertiliser use and the degree of soil compaction.

Based on the NPV analyses reported here there seems to be no justification to extend the top of the target range beyond 40. McKay et al. (2010) did obtain a critical Olsen P value corresponding to 97% of maximum yield that was slightly above 40 (43) for pastures in the absence of added N. But this was based on trials at only a limited number of sites, and does not at this stage justify a general increase in the recommended maximum level of Olsen P.

Environmental Considerations

The concentration of P in surface runoff is closely related to the level of available P in the soil – and hence the Olsen P test (Figure 8). Thus, any initiatives that result in increased Olsen P levels on dairy farms could increase P runoff into rivers, streams and lakes. However, changing the target range as recommended above is likely to have very little effect on the quantities of P running off New Zealand dairy farms for two reasons. Firstly, most farms already have Olsen P levels above the new recommended minimum threshold, and secondly, the upper threshold has not been changed.

The greatest threat to water quality is posed by farms that have Olsen P values considerably above the recommended target range. It is even possible therefore, that if the recommended target range can be made more credible by increasing the lower threshold to more closely match farmer practice, then it may be easier to convince those farmers with extremely high Olsen P values to gradually reduce these over time.

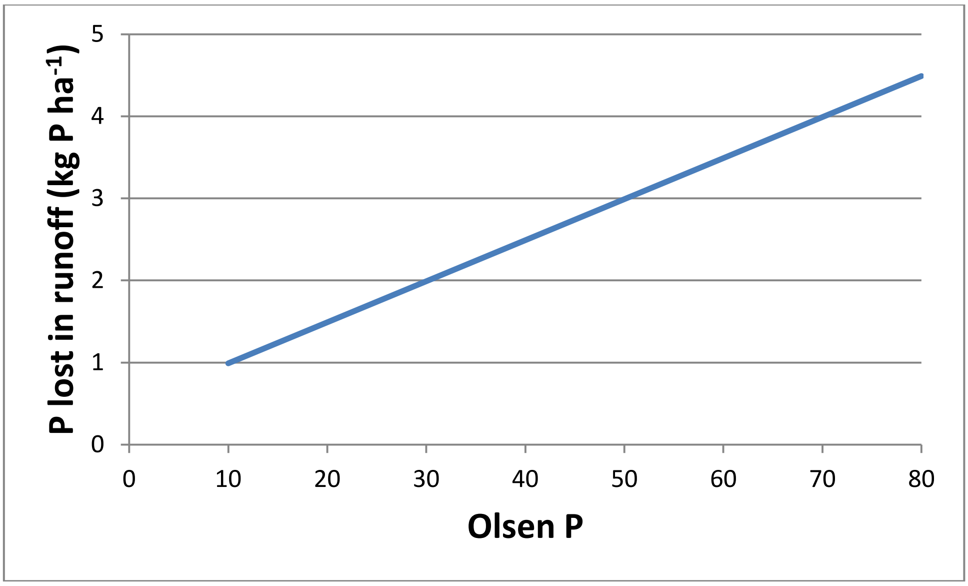

Figure 8. Relationship between Olsen P and P lost in runoff from a poorly-drained pallic soil with an annual rainfall of 1500 mm and with fertilizer P applied at the rate of 36 kg P ha^{-1}.y^{-1} (as estimated by OVERSEER® nutrient budgets 2009 – version 5.4.10)

Future work

The current calibration of the Olsen P test assumes implicitly that for each soil group there is a unique relationship between Olsen P and relative yield. This has proved to be a useful approach and has allowed data from a large number of trials to be aggregated to produce reasonable target ranges for Olsen P for different soil groups. However, as noted above, there is significant variation in the data around the fitted calibration curves and this places limits on the precision with which a soil test can be interpreted. Although some of this uncertainty is the result of random variation and could perhaps be reduced by more trial data, there are sound physical and biological reasons why calibration curves will vary from site to site. As long as it is implicitly assumed that there is a unique relationship between Olsen P and relative yield for a soil group, simply conducting more P response trials to add to the current database will not improve the calibration greatly.

If however, it is believed that some identifiable factors (e.g. high MS production or soil compaction) lead to a systematic change in the calibration curve, then research to clarify this may be justified. We do not envisage generating a "family" of calibration curves, with the level of precision that this would imply, but rather a simple decision support system which would guide farmers and consultants as to where in the target range they should be positioning their farm. This is already done for high producing farmers. The work by Mackay et al. (2010) points to some other areas that may warrant further investigation.

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