SOIL CHEMISTRY WHICH INFLUENCES POTENTIAL P LOSS

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Abstract
Previous studies have found dissolved reactive P (DRP) in drainage flow to be strongly related to calcium chloride extractable DRP in soil. The test 0.01 M $CaCl_2$-P can be used as an environmental test to identify soils at risk.

The objective of this study was to identify soils that were potentially at risk of losing P via subsurface drainage. This was achieved by using soil tests or markers that could predict the potential release of P from soil to soil solution.

Fifteen hundred soils were tested for 0.01 M $CaCl_2$ extractable P, Olsen-P, P Retention (PR) and carbon (C) on <2 mm fraction of dried soil. Relationships between 0.01 M $CaCl_2$ extractable P and the other tests were established.

Concentrations of 0.01 M $CaCl_2$-P ranged from 0 to 2 mg/L with the majority less than 0.1 mg/L (58%). There is an indication that soil type (or chemical species that is consistent within soil type) plays an important role in P release to solution. Low PR soils (< 40%) have potential to have high 0.01 M $CaCl_2$ – P values. High values of 0.01 M $CaCl_2$ - P can lead to large amounts of P lost into subsurface flow or drainage.

Introduction
The potential P-loss pathways can be described by overland flow (usually considered primary) and subsurface flow. Phosphate via these pathways is lost through particulate bound P and water-soluble forms of P: including both inorganic and organic forms of P. The amount of nutrient lost via subsurface flow is related to amount of rainfall and drainage (Rajendram et al., 1998).

It is generally accepted that eutrophication is accelerated when P concentrations exceed 0.015 mg/L in waterways (Hedley et al., 2002; Sharpley et al., 1996). Phosphorus loss from farms contributes to P levels in waterways such streams, rivers and lakes. The concentration in soil solution is typically an order of magnitude higher than DRP in waterways. It can be calculated that for a concentration of 0.015 mg/L P with 400 mm drainage, equates to only 0.1 Kg of P loss ha/year. Economically this is not a problem for the farmer, however it shows that small amounts of P lost from soil can cause large problems in the surrounding environment.

General consensus once held that phosphorus was not lost from soils from subsurface drainage. However, Hogg and Cooper (1964) found that P leached from a low phosphate retentive soil: Te Kopuru Sand (Northland). Jenny Edwards (1997) in her PhD study, similarly found very high losses (> 8 Kg/ha/year) on Wharekohe soils particularly as P levels

built up. Another study found elevated levels of P at 1 metre depth on pumice soils at Rerawhikaitu, which is part of a lake catchment (Ghani et al., 2005). These studies all showed that sub-surface P loss does occur.

McDowell and Sharpley (2001) found a relationship (Equation 1) between DRP in drainage water (subsurface P-loss) and soil 0.01 M $CaCl_2$-P (1:5 soil:solution ratio, with 30 min extraction).

$$DRP = 0.8 \times 0.01 \text{ M } CaCl_2\text{-P} \qquad\qquad [1]$$

Studies have shown a change point (a change in the relationship) between various available P tests (example Olsen-P) and $CaCl_2$-P could be established (Condron and McDowell, 2003; McDowell and Condron, 1999). It was speculated that PR was related to this change point. Models were generated which tried to predict 0.01 M $CaCl_2$ extractable P from an available P test and PR. Two are shown below for New Zealand soils (Equations 2 and 3).

Hedley et al. (2002):

$$CaCl_2\text{-P} = 0.11 + 0.054 \ e^{(0.015 \text{ OP})} - 0.002 \text{ PR} + 97 \ e^{(-0.299 \, . \, \text{PR})} \qquad [2]$$

McDowell & Condron (2004):

$$DRP = 0.069 \ (Olsen \ P \ / \ PR) + 0.007 \qquad\qquad [3]$$

The objective of this study was to identify soils that were potentially at risk of losing P via subsurface drainage. The relationship between soil tests and the potential release of P from soil to soil solution was also investigated.

Method
To estimate potential risk of phosphate loss from New Zealand soils, 1500 soils from different sites around New Zealand were analysed for 0.01 M $CaCl_2$ extractable P, PR and Olsen-P. A more in-depth study was also done on 500 soils where there was knowledge of the soil type and carbon (organic matter levels).

Soils were sampled to a depth of 7.5 cm, dried (at $< 40°C$) and ground (to < 2 mm) before analysis.

Olsen P was measured using the MAF, Soil Fertility Service Lab method to determine the levels of plant available phosphate in New Zealand soils. The method employs a $NaHCO_3$ extraction method developed by Olsen et al., (1954), where the phosphate concentration in the extract is determined by a phospho-molybdate method proposed by Watanabe and Olsen (1965) and Murphy and Riley (1962). Olsen-P was determined on a volume basis where 5 mL of soil (using a calibrated scoop) is extracted with 100 mL of 0.5 M $NaHCO_3$ and reported as Olsen-P mg/L.

Phosphate Retention (PR) was determined by shaking the soil with a buffered phosphate solution for 16 hours. The amount of phosphate remaining in solution was determined colorimetrically at 420 nm (Blakemore *et al.,* 1980).

Calcium chloride (0.01 M) extractable P was measured with 4 g soil sample to 20 ml of solution and shaking for 30 minutes at 185 rpm, and determined colorimetrically using the phospho-molybdate method.

Results and Discussion
The results from the 1500 soils analysed for 0.01M $CaCl_2$-P show that most soils (58 %) had a concentration less than 0.1 mg/L extractable P (Figure 1 & Table 1).

Figure 1 & Table 1: Population of 0.01 M $CaCl_2$ – P for 1500 soils from around New Zealand
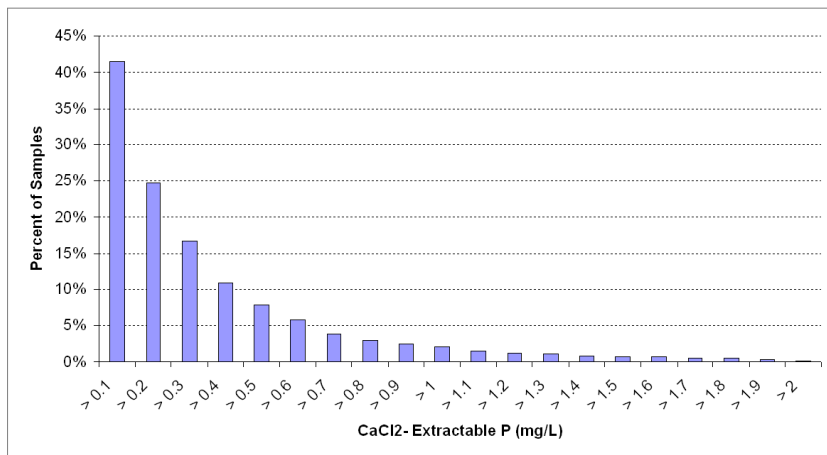
	0.01M $CaCl_2$ – P (mg/L)
Range	0 – 2.0
Median	0.07
Average	0.16

Forty-seven samples were also analysed for 0.01 M $CaCl_2$-P in quadruplet. Using these samples we can calculate the uncertainty in the test (95% confidence interval) at varying concentrations of 0.01 M $CaCl_2$-P. Table 2 shows the results of this investigation.

Table 2: Uncertainty of measurement for varying 0.01 M $CaCl_2$ extractable P concentrations.

	Detection Limit (mg/L)	Average Value (0.16 mg/L)	0.5 mg/L	Maximum Value (2.0 mg/L)
95% Confidence Limit	± 0.02	± 0.03	± 0.06	± 0.25

Using the median, maximum and eutrophication values, an estimate of how much P kg/ ha/ yr and the associated cost can be calculated. Table 3 shows the results of these calculations.

Table 3: Calculations of amounts of P lost and cost from different 0.01 M CaCl$_2$-P values.

0.01 M CaCl$_2$ - P (mg/L)	Estimated* Potentially Lost (Kg P / ha / yr)	Estimated[+] Potential Cost for 100 ha Farm
0.015 (Eutrophication)	0.06	~ $ 20
0.16 (Average Value)	0.64	~ $ 250
2.00 (Maximum Value)	8.0	~ $ 3,000

* Estimated using 400 mm of drainage calculated average from 10 years drainage data from Ruakura Research Centre, Hamilton (*pers. comm.* Mike Sprosen, AgResearch, Hamilton).
[+] Estimated using single super phosphate (SSP) at $345 per tonne.

The estimated P loss values are very similar to that found by McDowell et al., (2003). It is clear from the calculations that the amounts of P lost are very small especially when compared to the amount of P applied as fertiliser (typically ~70 Kg P / ha / yr on dairy farms). Economically these losses are not a concern; however, from an environmental point of view, these small losses can have a big impact. The average loss was approximately 10 times the eutrophication level.

The difference between the median and average values, show that the 'potential heavy polluters' skew the mean. Therefore, the soils where appreciable amounts of P may be lost need to be targeted or managed in order to reduce the losses from these soils.

In order to build relationships between 0.01 M CaCl$_2$-P and routinely performed soil tests, PR and Olsen P was compared against 0.01 M CaCl$_2$-P. Figure 2 shows the relationship between 0.01 M CaCl$_2$-P and PR, while dividing the samples into different Olsen-P groupings (shown by colour).

**Figure 2: Relationship between 0.01 M CaCl$_2$- P, Phosphate Retention & Olsen-P**
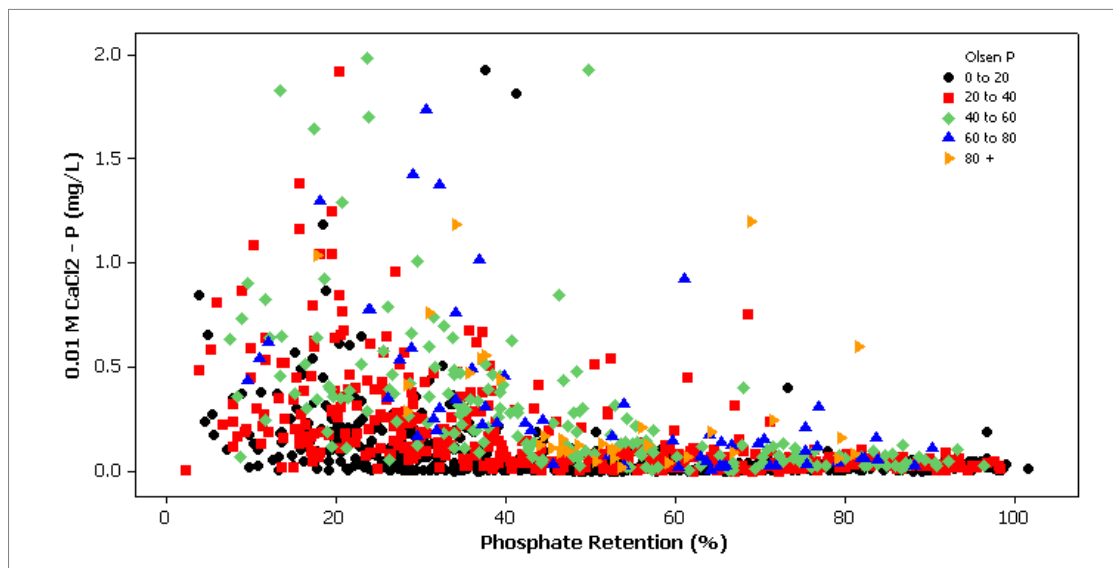
At higher levels of PR (> 40%) there was (in general) low values of extractable 0.01 M CaCl$_2$-P even in the soils which contained high Olsen-P concentrations. Below 40% PR there was a potential for higher 0.01 M CaCl$_2$-P values. There was also an indication that Olsen-P explained some of the variation between PR and 0.01M CaCl$_2$-P when soils had low PR status. This is developed in Figure 3, where the Olsen-P groupings are refined to 0 to 20, 20 to 40 and > 40 mg/L Olsen-P values and known peat samples are removed as they were later found to have a different relationship.

Figure 3: Relationship between 0.01 M CaCl$_2$- P, Phosphate Retention & Olsen-P
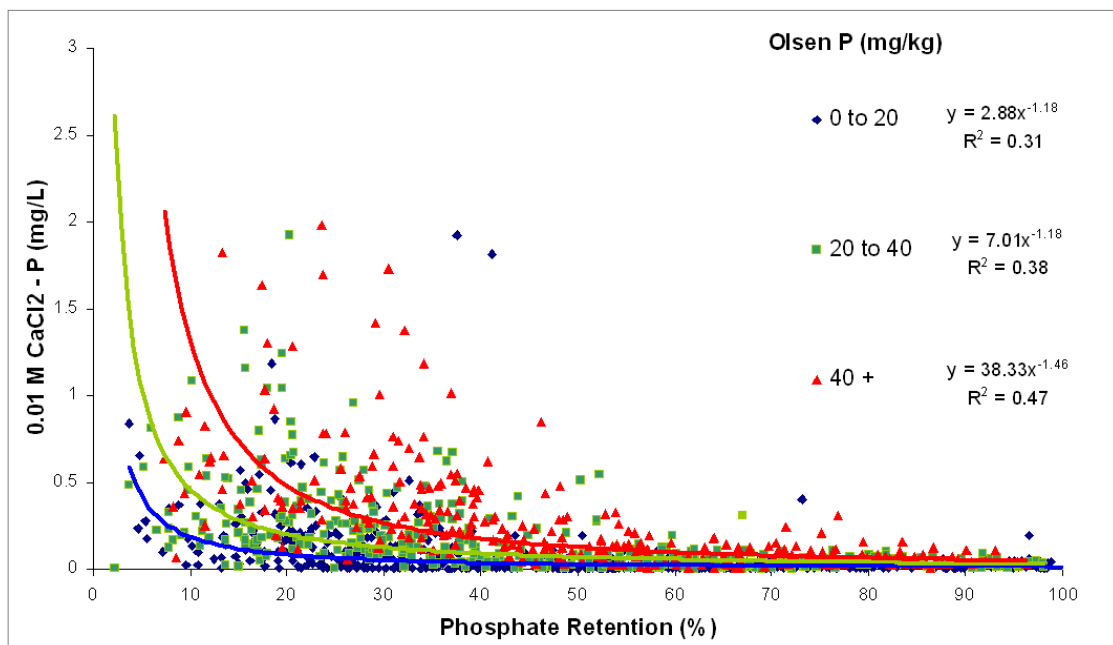
Despite the low correlation coefficients (R^2 of 0.31 to 0.47), there does appear to be a relationship. However, it is clear that Olsen-P and PR cannot completely describe the 0.01 M $CaCl_2$-P values measured. It was speculated that sample type (or a species consistent within a soil type) was playing an important role. Figure 4 shows the relationships with splitting the samples into four soil groups (sedimentary, ash, pumice and peat).

Figure 4: Relationship between 0.01 M CaCl$_2$- P, Phosphate Retention, Olsen-P and Soil Type
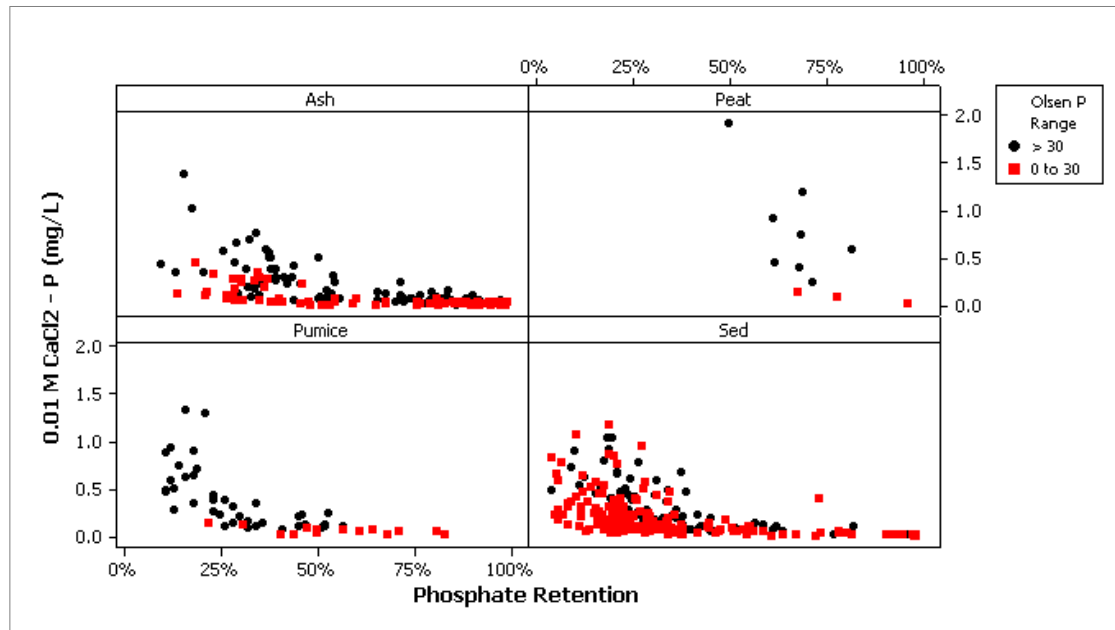
For the Ash, Peat and Pumice soil groups, the relationships between PR and 0.01 M $CaCl_2$-P appear well defined (R^2 = 0.6 - 0.7). The Peat soils show a different trend to the other soil types. The sedimentary soil type appears not to have as well defined relationship as the other soil groups, this is probably due to there being many more soil orders within the sedimentary group, compared to the others (Ash having; 3, Pumice; 1, Peat; 1, Sedimentary; 10). Further splitting the samples into these soil orders may give much better relationships.

An alternative way to look at the relationships between the three variables is plotting 0.01 M $CaCl_2$-P against Olsen-P while grouping the samples into PR groups by colour (Figure 5).

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Figure 5: Relationship between 0.01 M CaCl2- P and Olsen P
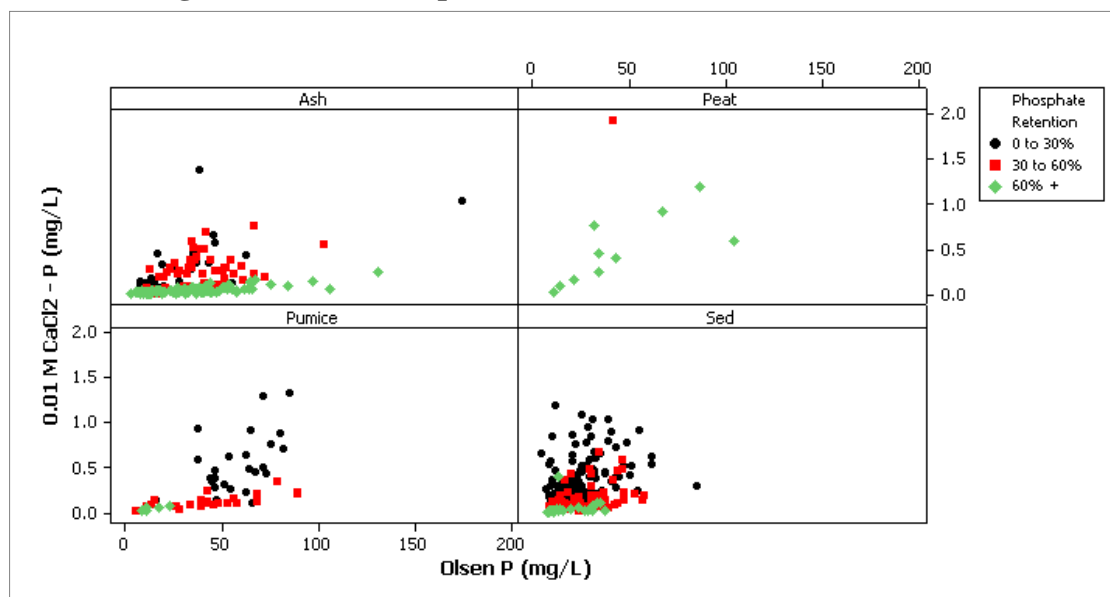
The graphs again show that in general, high PR (>60%) soils have a very low slope between Olsen-P and 0.01 M $CaCl_2$-P, when the PR decreases, the slope of the relationships appear to increase. However, the two variables cannot adequately describe 0.01 M $CaCl_2$-P by themselves, especially at low PR (<30%).

Conclusion

Phosphate Retention of less than 40% has a high potential for more 0.01 M $CaCl_2$ extractable P to come into solution.

There is an indication that soil type (or chemical species, that is consistent within soil type) plays an important role in P release to solution. There are also unknown factors within this study which we do not have information, such as fertiliser history (type, rate and time since last application).

There is the potential for 0.01 M $CaCl_2$-P to be a soil-P environmental test to identify soils which are at risk of losing P via drainage to the environment.

Future research: Finding the links to improve previous models (soil type / soil order, fertiliser history) and evaluating other chemistry that could influence P-loss in soils.

Acknowledgements

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