

OLSEN P METHODS AND SOIL QUALITY MONITORING: ARE WE COMPARING “APPLES WITH APPLES”?

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Abstract

Olsen P is a commonly used soil fertility and soil quality monitoring indicator. In New Zealand, Olsen P is widely used by the agriculture and horticulture industries to help assess on-farm nutrient management. It is also widely used by many regional councils in State of the Environment soil quality monitoring, and by many other researchers to study soil quality.

Soil can be measured on a volumetric (volume) or gravimetric (weight) basis prior to chemical extraction in a laboratory. We investigated if Olsen P results reported from these different methods by regional councils, the agriculture industry and other researchers are able to be compared. New Zealand fertiliser advice is based on a volumetric basis. We report the influence of laboratory method prior to chemical extraction, undisturbed bulk density, sieving methods and soil sampling depth.

Our results and analyses confirm that Olsen P data on a gravimetric basis is different from Olsen P data on a volumetric basis, when concentrations exceeded 10 ppm (i.e. mg/L or mg/kg). Comparing Olsen P results requires correcting data for undisturbed bulk density. In some cases variation can be wide particularly with soils of low bulk density or with Olsen P > 50 ppm. When undisturbed bulk density was used to convert Olsen P values to an equivalent basis median values still differed by about one third.

Sample depth (0-7.5 or 0-10 cm) had a small (4% on average) and significant effect on Olsen P. Differences were noticeably greater for samples with Olsen P > 60 mg/kg. While either depth provides suitable data for assessing the P status of soils, users should consider these differences in values when interpreting between the SOE and industry soil monitoring methods.

Olsen P when measured on a gravimetric basis negates the influence of bulk density. Undisturbed bulk density measurements must be incorporated into soil quality information if volumetric and gravimetric methods are to be compared on an equal basis, if data are to be compared to work done overseas, for the purposes of a mass balance (and between depths) and for incorporation into environmental soil P assessments.

We recommend that users of soil quality data pay careful note of the units for results reported by laboratories, and for interpretation of data such as subsequent comparison with guidelines. The differences in methodology discussed in this paper should be considered when developing and interpreting soil quality data.

Keywords: Olsen P, soil phosphorus, soil quality, bulk density

Introduction

Olsen P is a commonly used soil fertility indicator used by agricultural and horticultural industries to help assess on-farm nutrient management. It is also widely used by regional councils and many researchers to study soil fertility, soil quality, and interactions of soil and water.

Regional councils in New Zealand regularly monitor soil quality in State of the Environment (SOE) monitoring. Monitoring the state of the environment is a specific requirement for regional councils under the Resource Management Act 1991. Specific requirements are to report on the “life supporting capacity of soil” and to determine whether current practices will meet the “foreseeable needs of future generations” (Gray 2010).

A project popularly known as the “500 Soils Project” was set up from previous programmes for the purposes of establishing monitoring programmes for regional councils. The project involved 10 of the 16 regional authorities in 2000-2001 (Sparling et al. 2004). Many regional councils have continued soil quality monitoring and regularly report results (e.g. Gray 2010; Stevenson 2010; Taylor et al. 2010; Taylor 2011a; Sorensen 2012). Methods were established by Landcare Research and were recently published in a manual by the Land Monitoring Forum (e.g. Hill and Sparling 2009). Olsen P is one of a suite of soil quality indicators routinely measured.

The agricultural industry has for many years in association with current and former government and research organisations used soil fertility indicators such as Olsen P to measure soil fertility on farms for assessing nutrient and fertiliser requirements. For example, for pastoral farms, a very large body of research in soil fertility and pastoral yield response was undertaken (e.g. Cornforth and Sinclair 1984; Sinclair et al. 1997; Edmeades et al 2006). Much of this work has culminated in recommendations to avoid higher than needed soil fertility levels. For example, the established industry recommended guidelines for Olsen P levels on dairy farms of between 20 and 40 mg/L for sedimentary soils (depending on milk solids production level) were reported in Roberts and Morton (2009). Recommendations for other soil groups (ash, pumice and peat soils) are also detailed. This booklet was first produced in 1993 and is widely used.

Recently, we investigated if monitoring results such as Olsen P in State of the Environment soil quality monitoring by regional councils, by other researchers and in the agriculture industry are able to be compared with one another and with established industry recommended guidelines. We investigated if there are different monitoring and laboratory methods used, and if so, what the differences mean for interpretation.

This paper aims to raise awareness of and help quantify some of the key differences of soil quality monitoring commonly used in New Zealand, and provide recommendations for improved interpretation, reporting and further research.

Overview of selected laboratory methods

Soil can be measured on a volumetric (volume) or gravimetric (weight) basis prior to chemical extraction in a laboratory. In Australia for example, Rayment and Lyons (2011) detail soil chemical procedures. For Olsen P, Rayment and Lyons (2011) recommend as standard procedure weighing 5.0 g air-dry soil (<2 mm). Subsequent chemical extracts are

then undertaken. Olsen P when quoted on a gravimetric basis negates the influence of bulk density (McDowell and Condron 2004).

The Olsen P chemical extraction is a well defined, documented and routine test, so is not discussed here in detail. It appears that the way the soil is prepared once it is received in a bag by the laboratory is a key difference between some New Zealand laboratories, before any subsequent chemical extraction. In New Zealand, for example, several large commercial laboratories measure soil received in the laboratory prior to Olsen P chemical extraction by volume. From our investigation we have found that, for example, Hill Laboratories, the ARL laboratory and some commercial laboratories measure the soil on a volume basis. There may be others.

The Landcare Research laboratory and many researchers measure soil gravimetrically prior to chemical extraction. In this paper we have not attempted to detail all laboratory methods or from all New Zealand laboratories.

The extensive Ministry of Agriculture and Fisheries (MAF) and AgResearch trials (e.g. Cornforth and Sinclair 1984; Sinclair et al. 1997; Edmeades et al 2006; Roberts and Morton 2009) on which field-calibrated pastoral nutrient response curves and soil fertility recommendations were and are currently based were developed from the volumetric method. Sinclair et al. (1997) reported that the Ministry of Agriculture and Fisheries adopted the Olsen P test in the mid 1970s as the standard on which to base fertiliser advice for New Zealand farms. Sinclair et al. (1997) reported that the soil test was actually a modification of the original test, in that a volume rather than a weight of soil was used. Mountier et al. (1966) reports the use of routine volumetric sampling in New Zealand laboratories for a variety of tests. Grigg (1977) reported that Olsen P was measured on a volumetric basis as it yielded a better coefficient of determination to the relative yield of pasture and arable crops than if measured on a gravimetric basis. Grigg (1977) also reported several other reasons for adoption of the modified test.

Methods, results and comparisons

This section presents brief methods and results from recent studies for a variety of soils and regions across New Zealand evaluating effects of volumetric and gravimetric methods and undisturbed bulk density, soil depth and sieving methods.

Undisturbed bulk density measurements must be incorporated into soil quality information if volumetric and gravimetric methods are to be compared on an equal basis, if data are to be compared to work done overseas, for the purposes of a mass balance (and between depths) and for incorporation into environmental soil P assessments.

Comparison of volumetric and gravimetric methods and undisturbed bulk density – Southland soils

This study compares volumetric and gravimetric measurements of soil for Olsen P extraction and bulk density.

Approximately 40 pastoral soils of the Brown, Gley and Organic soil orders were sampled from coastal Southland (0-7.5 cm depth). These were air-dried, crushed, sieved < 2-mm and analysed for Olsen P concentration using gravimetric and volumetric methods, the latter utilizing a 2 mL scoop. Samples for undisturbed bulk density (0-7.5 cm) were also collected.

A comparison of gravimetric and volumetric data indicated a wide variation (Figure 1). However, when split into quartiles according to bulk density good relationships were found between the two methods. In general, data indicated that the disparity between the two methods increases with decreasing soil bulk density (Figure 1). For example, the relationship was closest to 1:1 (ie slope = 1.016; Figure 1) for soils with bulk density $> 0.87\text{g/cm}^3$. Caveats to the use of this data are that they only represent three soil orders, pastoral soils (of 0-7.5 cm depth) and have a limited pH and P concentration range.

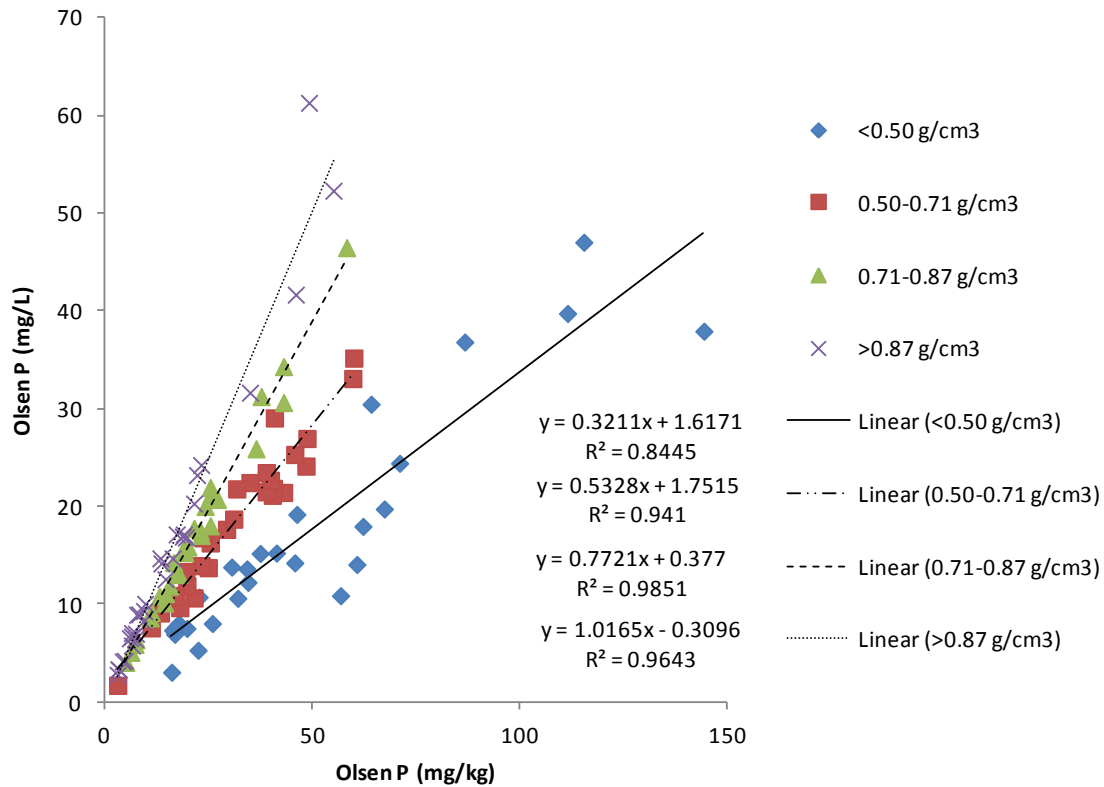


Figure 1: Comparison of Olsen P values for volumetric (mg/L) and gravimetric (mg/kg) methods with bulk density (g/cm^3) grouped by bulk density quartile for Southland region soils.

Comparison of volumetric and gravimetric methods

In this study, 55 soil samples were collected over several soil orders including the Allophanic, Brown, Gley, Granular, Pallic, Recent, and Ultic soil orders from the Auckland, Wellington and Marlborough regions. Samples were collected, as per sampling protocols (Hill and Sparling 2009), from 0-10 cm depth from a 50 m transect per site as part of the three regional council's SOE monitoring program for indigenous forest/scrub and dairy pasture land uses. Sample cores per site were bulked and mixed. For the Marlborough and Wellington regions, once mixed, samples were split to send a subsample to each laboratory. For the Auckland region, samples were sent to Landcare Research, then the laboratory sample was sent to Hill Laboratories. All samples were analysed for Olsen P at Hill Laboratories, Hamilton (volumetric basis, results in mg/L), and also at Landcare Research, Palmerston North (gravimetric basis, results in mg/kg) by their standard methods. Note that in this paper, results expressed in ppm mean either mg/L or mg/kg. Three samples for undisturbed bulk density at 0-7.5 cm were also collected per transect using stainless steel rings, with a 3 cm subsample ring then extracted for analysis at Landcare Research.

Figure 2 shows a comparison of the measured gravimetric and measured volumetric data split into quartiles according to bulk density. The relationships in Figure 2 indicated a slope range of 0.67-0.87, suggesting that gravimetric values of Olsen P were greater than for volumetric values.

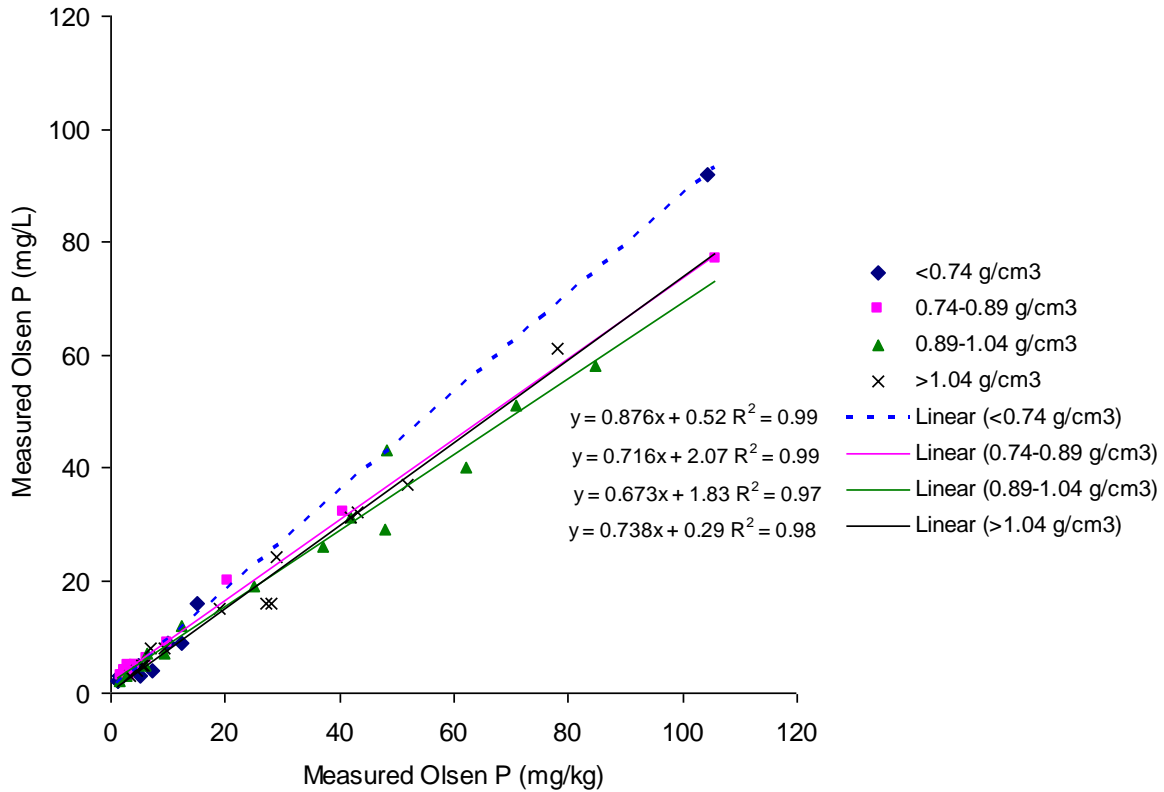


Figure 2: Comparison of Olsen P values for volumetric (mg/L) and gravimetric (mg/kg) methods with bulk density (g/cm³) grouped by bulk density quartile for Auckland, Wellington and Marlborough region soils.

Gravimetric and volumetric treatments were not significantly different ($p=0.116$, paired t-test after data log transformed). However, samples with Olsen P values greater than 10 ppm were consistently higher when measured gravimetrically, while both methods gave similar results for samples with values below 10 ppm. There were 33 samples with Olsen P <10 ppm. These include 26 indigenous sites from Auckland and 7 from Wellington regions (Table 1).

Bulk density was then used to convert the volumetric results (from Hill Laboratories) data to a gravimetric result. Some Olsen P values have been received as rounded values which may affect comparisons especially for low values. The calculated gravimetric result (i.e. volumetric treatment converted using bulk density) was then significantly higher ($p<0.0001$, paired t-test after data log transformed) than the measured gravimetric treatment for this <10 ppm dataset.

Table 1. Comparison of volumetric and gravimetric methods between two laboratories for samples with Olsen P <10 ppm. Some values have been rounded.

Sample	Olsen P value		Bulk Density (g/cm ³)	Hill Lab Olsen P with field bulk density conversion to (mg/kg)
	Hill Laboratories volumetric (mg/L)	Landcare Research gravimetric (mg/kg)		
Average	4.7	4.7	0.81	5.8
Median	4.0	4.1	0.77	5.4
Std dev	2.1	2.9	0.19	2.6

Note: Four values of Olsen P >10 as a result of gravimetric conversion

The remaining 22 samples with Olsen P >10 ppm are presented in Table 2. Gravimetric results were on average 33% greater than those from the measured volumetric method (p<0.0001, paired t-test after data log transformed) - but note that these results have not yet been converted using bulk density.

Bulk density was then used to convert the volumetric results (from Hill Laboratories) data to a gravimetric result for the remaining 22 samples with Olsen P >10 ppm. The calculated gravimetric result (i.e. volumetric treatment converted using bulk density) was then significantly higher (p<0.0003, paired t-test after data log transformed) than the measured gravimetric treatment for this dataset.

When bulk density was used to convert measured volumetric values to a gravimetric comparison, the average converted Olsen P value (38.8 mg/kg) was 17% less than the average measured value (47 mg/kg; Table 2). When bulk density was used to convert measured volumetric values to a gravimetric comparison, the median converted Olsen P value (28.5 mg/kg) was 32% less than the median measured value (42 mg/kg; Table 2).

Similarly, bulk density was also used to convert the gravimetric results (from Landcare Research Laboratory) data to a volumetric equivalent result (Figure 3). The calculated volumetric result (i.e. gravimetric treatment converted using bulk density) was then significantly higher (p<0.001, paired t-test after data log transformed) than the measured volumetric treatment for this dataset. The median converted value (40.7 mg/L) was 32% greater than the median measured value (31 mg/L; (Figure 3).

Table 2. Comparison of volumetric and gravimetric (i.e. laboratory) differences for samples with Olsen P >10 ppm. Some values have been rounded.

Sample	Olsen P value		Bulk Density (g/cm ³)	Hill lab Olsen P with field bulk density conversion to (mg/kg)
	Hill Laboratories volumetric (mg/L)	Landcare Research gravimetric (mg/kg)		
Average	35.4	47.0	0.98	38.8
Median	31.0	42.0	1.00	28.5
Std dev	21.1	27.1	0.16	30.6

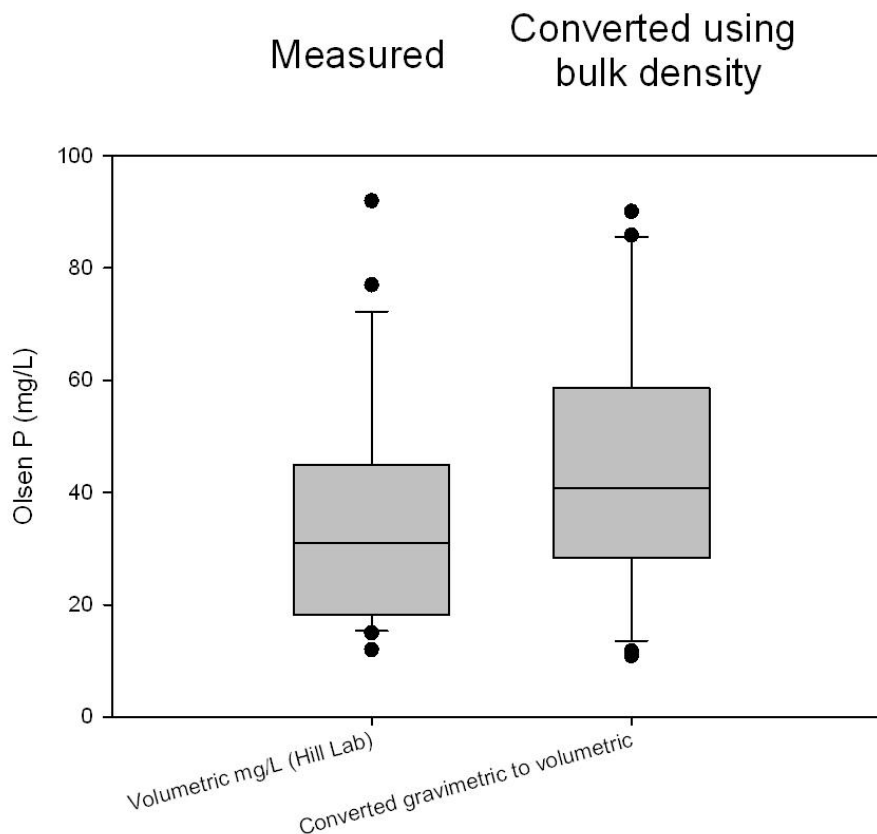


Figure 3: Comparison of Olsen P values for measured volumetric (mg/L) and measured gravimetric that has been converted to equivalent volumetric basis using undisturbed bulk density for Auckland, Wellington and Marlborough region soils.

Comparison of Olsen P measured at 0-7.5 cm and 0-10 cm soil depths

Soil quality monitoring by regional councils is undertaken at 0-10 cm soil depth across all land uses (Hill and Sparling 2009). Soil sampling by the fertiliser and agricultural industries for pastoral landuse is undertaken at 0-7.5 cm soil depth (Roberts and Morton 2009). The sampling depth for pastoral yield response research and soil fertility guidelines is 0-7.5 cm.

To assess the effect of these two soil depths on Olsen P values, 38 pastoral soil samples were taken from separate sites at two depths (0-10 cm and 0-7.5 cm) in the Waikato and Marlborough regions. Adjacent 0-10 cm and 0-7.5 cm samples were taken every one metre of a 5 m transect, per site, for the Waikato samples.

Soil orders sampled included Allophanic, Brown, Gley, Organic, Pumice and Recent Soils. The Olsen P analysis was carried out gravimetrically at Landcare Research, Palmerston North for Waikato (EW) samples and results are presented gravimetrically (mg/kg, Table 3). The Olsen P analysis was carried out volumetrically at Hill Laboratories for Marlborough (MDC) samples and results are presented volumetrically (mg/L, Table 3). For the purposes of this analysis the comparison is for depth, not method, so bulk density was not included.

Olsen P was on average 4% higher for the 0-7.5 cm sample depth compared with 0-10 cm, and statistically significant ($p= 0.0075$, paired t-test after data log transformed). Differences

were noticeably greater (either more negative or more positive) for samples with Olsen P values greater than 60 ppm compared with lower Olsen P values.

Table 3. Comparison of the effect of sample depth on Olsen P in pastoral soils from Waikato and Marlborough regions. Some values may have been rounded. EW samples were reported gravimetrically (mg/kg), MDC samples were reported volumetrically (mg/L).

Sample	Olsen P (mg/L or mg/kg)	
	0-10 cm sample depth	0-7.5 cm sample depth
Average	63.6	67.4
Median	51.8	51.4
Std dev	59.3	62.8

Comparison of the effect of 4 mm sieving before air drying and grinding to 2 mm.

Soil sieving and preparation methods can vary. For example, soil is commonly air dried and crushed to pass through a 2 mm sieve. Driven by the requirements of the anaerobically mineralised nitrogen analysis, Landcare Research carries out an additional step of 4 mm sieving before air drying the sample and grinding to 2 mm. The effect of this additional sieving step on soil quality parameters has not been published.

To investigate effects of sieving preparation, 39 samples from the Waikato region were analysed for Olsen P at Landcare Research, Palmerston North and results are presented gravimetrically (mg/kg). Samples sieved to 4 mm followed by air drying and grinding were compared to those which just had obvious roots removed by hand (no sieving) before air drying and grinding.

The treatments were significantly different ($p=0.0304$). Samples sieved to 4 mm before air drying and grinding were on average 4% less than those with hand removal of obvious roots (Table 4). Olsen P values in 14 samples were greater with 4 mm sieving and 25 were lower compared with hand removal of obvious roots. Differences ranged from -25 to 20 mg/kg. Replication was considerably better below values of 50 mg/kg, which includes the recommended ranges for most crops and pasture.

Table 4. Comparison of soil sample preparation before drying on Olsen P values.

Sample	Olsen P (mg/kg)	
	Hand removal of roots	4 mm sieving
Average	66.8	64.1
Median	55.9	49.4
Std dev	60.3	62.2

Discussion

Our results and analyses show that Olsen P data on a gravimetric basis is different from Olsen P data on a volumetric basis, but only significant for concentrations > 10 ppm. This suggests that either method is suitable for measuring and reporting Olsen P values below 10 mg/kg and 10 mg/L. Comparing results with values > 10 ppm requires correcting data for undisturbed field bulk density. There was one noticeable consistency across several studies

presented in this paper. Reproducibility of Olsen P data was much poorer above values of 50 ppm. Rajendram et al. (2003) suggested that conversion to volumetric from gravimetric measurement may not be straightforward, possibly due to chemical or other factors. Rajendram et al. (2003) also reported poorer relationships between volumetric and gravimetric methods for organic soils with low bulk densities than for sedimentary soils, a similar result as for organic soils sampled in Southland.

Whether or not Olsen P exceeds the current agronomic and SOE monitoring targets is important to regional councils and values above recommended guidelines would be considered to exceed soil quality targets. Many regional councils report SOE monitoring in relation to whether or not indicators are within or exceed relevant guidelines (e.g. Gray 2010; Stevenson 2010; Taylor 2011a). There has been some debate on the target values for Olsen P in regional council SOE reporting. Initial provisional SOE reporting targets were developed by Sparling et al (2008) based on crop production. For pastoral agriculture, the Olsen P SOE guideline of Hill and Sparling (2009) was generally considered too high. Recently Olsen P SOE guidelines have been revised (Taylor 2011b). For example, the current pastoral Olsen P SOE target values for sedimentary and organic soils are 20-35 (Taylor 2011b). Industry guidelines such as those in Roberts and Morton (2009) are also widely used to compare with soil quality results. However, there is increasing interest in research showing a greater risk to water quality as soil Olsen P concentrations increase (e.g. McDowell et al. 2003).

A perusal of some of the New Zealand published literature suggests that on some occasions Olsen P is reported on a gravimetric or volumetric basis interchangeably, or with direct comparison with guideline values of different units. Similarly, a perusal of regional council SOE soil quality reports over the last decade reveals that some report Olsen P on a gravimetric basis while others on a volumetric basis. Reports viewed were all clear on the units reported. Some were clear if they had converted gravimetric results to volumetric using bulk density. There were examples of publications comparing gravimetric results with the volumetric based industry guidelines. Also apparent was that the Land Monitoring Forum manual Olsen P recommended guidelines did not report measurement units. Similarly, some fertiliser industry publications did not report units. We note that early publications (e.g. Sparling et al. 2004) were clear that gravimetric results were converted to a volumetric basis using bulk density data. Rajendram et al. (2003) also reported some confusion or unawareness of volume and weight methods.

Bulk density must be incorporated into soil quality information data if the data are to be compared to work done overseas, for the purposes of a mass balance (and between depths), for soil comparisons, and for incorporation into environmental soil P assessments. When soil quality data are expressed volumetrically then comparisons can be made with New Zealand fertiliser industry guidelines. This is particularly important as sample bulk densities move below or above a value of 1 g/cm^3 , as illustrated in some results in this paper. Similarly, for example, a sedimentary soil with bulk density of 1.17 g/cm^3 , a measured Olsen P of 33 mg/kg has an equivalent calculated Olsen P value of 39 mg/L . A sedimentary soil with bulk density of 0.86 g/cm^3 , a measured Olsen P of 71 mg/kg has an equivalent calculated Olsen P value of 61 mg/L .

Sample depth had a small (4% on average) effect on Olsen P. Differences were noticeably greater (either more negative or more positive) for samples with Olsen P values $> 60 \text{ mg/kg}$ (Waikato samples). For the samples taken in the Waikato, pasture is regularly renewed so it is likely the soil is ploughed at least every 10 years. Unploughed land is likely to show a greater

gradient down the first 15 cm of the profile. Coad et al. (2010) reported greater differences in Olsen P at 0-7.5 cm of approximately 15% on average compared with 0-10 cm depth. While either depth provides suitable data for assessing the P status of soils, users should consider these differences in values when interpreting between the SOE and industry soil monitoring methods.

The effect of sieving before drying was not consistent compared to the hand removal of roots. There may be several factors impacting on the Olsen P result including effects of the roots themselves on the adjacent soil and how much this soil is removed with the roots (e.g. roots depleting P in the immediate vicinity of the root, root extrudes extracting P, transfer of P from less bioavailable pools; Schachtman et al. 1998). The variability in the data suggests a number of unaccounted for processes and/or the amount of soil removed with roots varied. Spatial variation may also be a factor.

Some caution should be applied with our preliminary results given sample sizes, limited range of soil orders and some variation on methods. For one of the studies, bulk density measurements at 0-7.5 cm were used to help evaluate Olsen P at 0-10 cm so some caution should be applied. While we attempted to minimise variation, and have a range of soils, there is a potential risk of type I or II statistical errors. Further research is recommended to quantify and minimise errors associated with re-sampling, depth and spatial variation. It may be helpful to also quantify dried sample weights and volumes for each method. Further research is recommended to evaluate the implications between some of the methods in this paper.

There are other aspects of soil quality that users should be aware of but one is only briefly mentioned here, as these are beyond the scope of this paper. For example, gravels and stones are a soil property affecting measurements such as Olsen P. Rajendram et al. (2011) showed that the exclusion of the gravel fraction prior to analysis (common laboratory practice) would have lead to higher Olsen P recommendations required to maintain maximum pasture production. Testing the soils with gravel was more representative of the original sampled soil, particularly if the soils contain large amounts of gravel. The exclusion of gravel will also have implications on other chemical tests in the soil. Greater losses of P may also be likely in gravelly soils so the percentage of stones > 2 mm should also be considered.

There are other considerations for further research or comparison. There is also need for investigating the effects of gravimetric, volumetric and other laboratory methods on other soil quality indicators, and whether assumptions and methods from earlier studies and methods are still used routinely today. The use of near infrared reflectance (NIR) techniques and other new technologies are likely to mean other differences in methodology such as for organic matter and nitrogen measurements. There is also likely to be scope for potential utilisation of extensive industry results to help characterise the state of the environment and reporting to aid resource management, so this should be investigated.

Conclusions

From our investigations we conclude that there are some key differences in soil quality monitoring approaches in New Zealand.

- Many commercial laboratories and some researchers measure and report Olsen P on a volumetric basis. New Zealand fertiliser industry guidelines for Olsen P are measured on a volumetric basis. For simplicity, units have not always been reported. Some research laboratories and researchers measure and report Olsen P on a gravimetric (weight) basis.

- Preliminary results and analyses show that Olsen P data on a gravimetric basis is different from Olsen P data on a volumetric basis. In some cases variation can be wide particularly with soils of low bulk density. The variation between the methods can increase with decreasing bulk density or as bulk density moves away from 1 g/cm³.
- Comparing volumetric and gravimetric results on an equal basis requires correcting data for undisturbed bulk density, but results can be variable.
- When bulk density was used to convert measured volumetric and measured gravimetric values that were converted to an equivalent volumetric basis using undisturbed bulk density, median values differed by about one third.
- Sample depth (0-7.5 or 0-10 cm) had a small effect on Olsen P.

We recommend

- that users of soil quality data pay careful note of the units for results reported by laboratories and for interpretation of data such as subsequent comparison with guidelines;
- that where needed clear statements are reported for use of conversion methods; and
- that the differences in methodology are taken into consideration for resource management decisions, when developing policies such as for managing to limits for freshwater management, and when interpreting soil quality data and monitoring programmes.

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