PRELIMINARY STUDY OF THE POTENTIAL FOR PHOSPHORUS LOSS WITH THE DEVELOPMENT OF ORGANIC SOILS

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Abstract

Organic Soils (organic matter concentration > 30%) cover 200,000 ha in New Zealand, of which around 67,000 ha have been converted for intensive land use (*viz*. dairy). However, Organic Soils have a number of properties that can exacerbate P losses including: high porosity and hydraulic conductivities and poor P retention, otherwise known as anion storage capacity (ASC). Studies have indicated that the physio-chemical properties of Organic Soils change quickly after initial development. However, the rate at which properties change and their influence on P loss is not well established. We hypothesized that Organic Soils have a potential to lose more P than other soil orders in the same region, and that the rate of P loss changes with time since development due to changes in soil properties. Ninety three paddocks were sampled containing approximately equal numbers of soils from the Organic, Gley and Podzol Soil orders in a coastal Southland catchment. Water extractable P (WEP), as an indicator for potential P loss in surface runoff, increased in soils with low ASC and/or high Olsen P concentration. Many of these soils were Organic Soils that had only recently been put into production. In contrast to Gleys and Podzols, the WEP concentration in Organic Soils quickly decreased with time since development to reach a near steady state after approximately 25 years. A mass balance confirmed that Organic Soils had lost more P than other soil orders, but also suggested that this decreased with time. The results of this study indicate that P losses from Organic Soils are potentially large but decrease with time since development and that using strategies to mitigate P loss is especially important within the first 25 years of development.

Introduction

In recent decades the area under dairying has increased in New Zealand. Much of this has been accommodated by the conversion of land into dairying that was originally considered of marginal use due to properties like poor drainage or fertility. With intensification of land use the use of phosphorus (P) fertiliser in New Zealand increased 128% in the period 1990-92 to 2002-04 (OECD, 2008). While there are obvious economic advantages to enhancing soil fertility by adding fertilisers, P is a finite resource with some concerns about supply and it is the most expensive macro-nutrient applied to land (Edmeades et al. 2006; Gilbert 2009). Additionally, P inputs from intensively farmed land (especially dairying) have been linked to poor water quality via accelerated aquatic eutrophication (Abell et al. 2010; Ballantine et al. 2010). These issues may be exacerbated on soils with poor capacities for P retention, for example, Organic Soils.

Organic Soils are estimated to cover 200,000 ha in New Zealand (Gibbs 1980). Many of these are in lowland areas and have been drained to improve aeration and resistance to physical damage from machinery and stock (O'Connor et al. 2001). Drainage can accelerate the rate of erosion (Marttila and Kløve 2010) and the mineralisation of organic matter (O'Connor et al. 2001), as well as the desorption of P from redox reactions within soils (Stepniewska et al. 2006). These processes can result in considerable P losses. Nevertheless, high pasture production on Organic Soils can be achieved with P fertiliser application. On a volumetric basis, Olsen P is typically maintained at higher concentrations than in better quality mineral soils. For example, the Olsen P target ranges to sustain 97% of maximum pasture production are 35–45 mg P/L for peat soils and 20–30 mg P/L for ash soils (Roberts and Morton 1999). Olsen P concentration and anion storage capacity (ASC) are related to the potential for P loss from soil to water (McDowell and Condron, 2004). Given that Organic Soils have a very low ASC, but may be maintained at a high Olsen P, we hypothesize that Organic Soils are a large source of P loss. With development, O’Connor et al. (2001) showed that the rate of change in Organic Soil properties slowed. Specifically the ASC of peat soils in the Waikato increased, presumably as the soil became more “mineral like”. Since ASC is one of the main factors influencing P loss (McDowell and Condron, 2004) we therefore hypothesize that this will translate into a decrease in the potential for P loss over time.

Methods

Soils were sampled from a coastal Southland catchment, southeast of Invercargill in an area receiving approximately 1200 mm annual rainfall. Soils were poorly-drained and from the Organic, Gley and Podzols Orders. Farming in the catchment was traditionally sheep, with some dairy support, but is now dominated by dairying. Using soil maps, approximately 30 paddocks were chosen of each Soil Order as well as some undeveloped “reference sites”. A questionnaire detailing the development and management histories of each paddock was completed with land owners. Data from the questionnaire was used to explain variation in each paddock’s soil chemical data. Information included the time since each paddock’s original conversion from scrub/native bush, the frequency and method of cultivation, pasture and forage crop maintenance and capital P fertiliser inputs, and stocking type and rate.

Samples were collected in July 2012 from 93 paddocks at 0-7.5 cm and 30-37.5 cm (below the plough layer) depths. Samples were air-dried, ground and sieved < 2 mm. Soils were analysed for pH (in water), Olsen P (Olsen et al. 1954), total P (TP via perchloric-nitric acid digestion), water-extractable P (WEP; McDowell and Condron, 2004), calcium chloride-extractable P ($CaCl_2$-P; McDowell and Condron, 2004), the degree of P sorption (DPS; via oxalate extractable Al, Fe, Ca and P), organic carbon (C) and organic matter (OM), ASC (Saunders, 1965), and bulk density (BD). Data were used in a statistical analysis (stepwise and best subsets regression) to determine the variable (e.g. test or tests) that accounted for most of the change in WEP and $CaCl_2$-P, which were used as surrogates for the potential for P loss in surface runoff and sub-surface flow, respectively.

A mass balance was also conducted to determine how much P had been lost since the paddock was developed. In keeping with McDowell (2008), P losses from 0 – 7.5 cm depth were determined using the model:

$$Loss_n = \sum_{i=0}^{n}([Input_i - Output_i] + Soil_{n=0}) - Soil_{i-n}$$

Whereby losses of P are equal to the sum of soil P concentration (kg P ha^{-1}; after accounting for BD) before development ($Soil_{n=0}$; assumed to equal TP in undeveloped sites) and difference between input and outputs of P from time zero to the year of sampling (kg P ha^{-1}), minus soil P concentration (kg P ha^{-1}) at the time of sampling ($Soil_{i-n}$). Inputs and outputs were derived via the Overseer® nutrient budget program and survey data collected during sampling. Plotting the estimated losses against age (n = 1 year) of development, and fitting a simple linear regression, yields a slope equivalent to the mean loss of P (kg ha^{-1} yr^{-1}) with time.

Results and discussion

Among Soil Orders, Organic Soils contained on average lower TP, BD and ASC, but greater Olsen P, WEP, C and $CaCl_2$-P (0-7.5cm depth only) (Table 1). This is consistent with the increase in WEP with increasing Olsen P or decreasing ASC (McDowell and Condron, 2004; Figure 1). Many of the Gley and Podzol Soils were enriched with C, but maintained a greater ASC than the Organic Soils, especially at depth. Variation in $CaCl_2$-P was very large (Coefficient of variation often > 50%), although the exact reason for this was unclear.

Table 1. Mean and in parentheses the standard error for selected physio-chemical properties for each soil order at the 0-7.5 and 30-37.5cm depths.

Soil/depth	Total P (mg/kg)	Olsen P (mg/kg)	WEP (mg/L)	$CaCl_2$-P (mg/L)	Bulk density (g/cm^3)	pH	ASC (%)	C (g/kg)
0-7.5 cm								
Gley	1011	37	0.149	2.246	0.68	4.6	47	266
	(164)	(5)	(0.032)	(1.553)	(0.10)	(0.2)	(9)	(51)
Organic	822	42	0.184	1.465	0.54	5.0	32	311
	(65)	(5)	(0.023)	(0.456)	(0.05)	(0.1)	(5)	(29)
Podzol	1026	23	0.081	0.509	0.82	4.7	67	145
	(93)	(2)	(0.005)	(0.228)	(0.03)	(0.1)	(3)	(19)
30-37.5 cm								
Gley	571	21	0.059	0.075	0.89	4.2	73	182
	(135)	(4)	(0.013)	(0.013)	(0.10)	(0.2)	(8)	(48)
Organic	414	23	0.106	5.425	0.66	3.9	37	321
	(51)	(3)	(0.012)	(1.652)	(0.05)	(0.1)	(6)	(33)
Podzol	530	13	0.051	0.066	0.93	4.3	82	110
	(74)	(2)	(0.003)	(0.011)	(0.03)	(0.1)	(3)	(17)

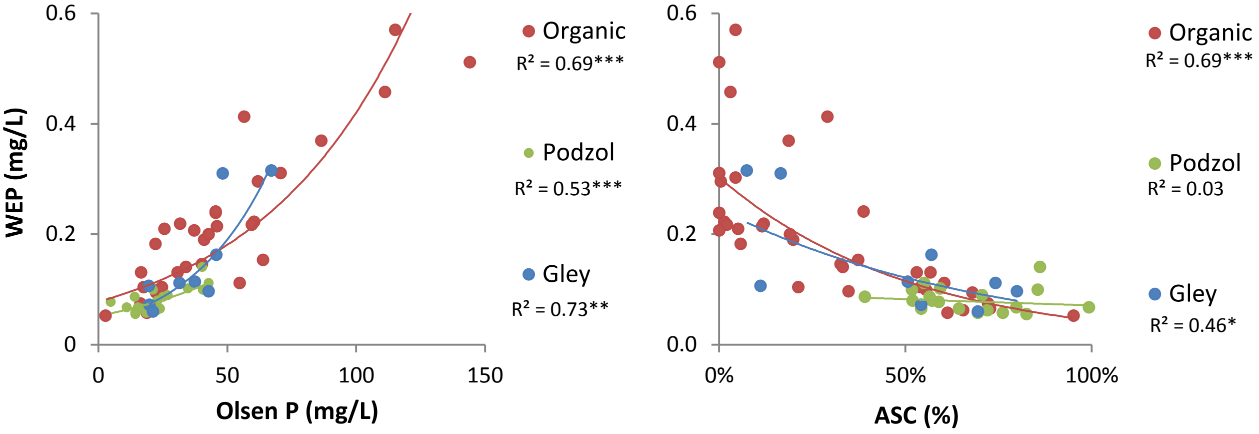

Figure 1. Relationship between WEP and Olsen P (left) and anion storage capacity (right) for Organic, Podzol and Gley Soils sampled at the 0-7.5cm depth.

Interestingly, the greatest Olsen P and WEP concentrations were in Organic Soils with ASCs in the range of < 1% to 19%. This suggests that these soils are likely to lose much P to surface runoff (McDowell and Sharpley, 2001). Organic Soils typically have a low ASC because they possess little mineral soil containing P-sorbing metal-oxides (Zak et al. 2004). This is potentially worsened by the presence of organic anions that may compete with orthophosphate for sorption sites (Gu et al. 1994; Hinsinger 2001). The high porosity and hydraulic conductivity in Organic Soils also promotes the interaction and flux of P, via high surface areas, from the soil matrix into flowing water (Stutter et al. 2005). However, it is possible that WEP may have been partially enriched by P released when soils were re-wetted: this is more likely to occur in organic than mineral parent material soils (e.g. Olila et al. 1997).

Incorporating the variable, time since development, WEP concentrations were greatest in Organic Soils that were recently developed and decreased over time to reach a plateau after about 25 years (Figure 2). No such relationship was noted for Gley or Podzol Soils. A best subsets regression indicated that this relationship in Organic Soils was due to combined changes in, order of priority, Olsen P, ASC, BD and soil pH. Both drainage and cultivation promote mineralisation of organic matter (Armentano and Menges 1986; Laiho 2006). Although not directly related, mineralization of organic matter and physical settling of soil will likely cause increases in BD and the mineral proportion of the soil, thus increasing soil ASC. Lime was applied to many of the paddocks to increase soil pH but will also increase organic matter mineralization and influence the availability of P by controlling levels of metal oxides that can precipitate with P (Wolf 1999).

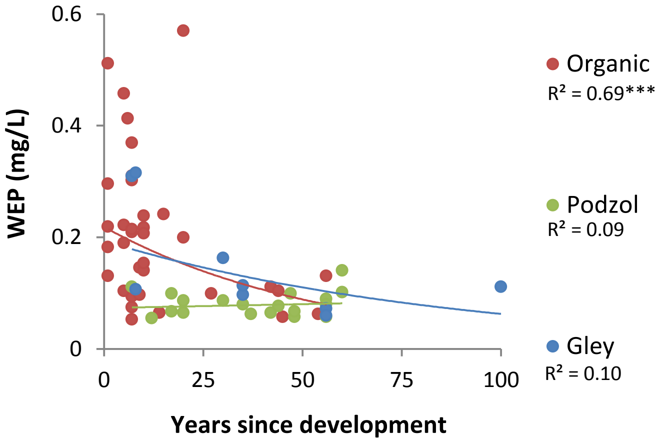

Figure 2. Relationship between WEP and years since development for soils sampled at the 0-7.5cm depth.

By plotting the P loss estimated from the mass balance model against the years since development we calculated the mean annual P loss from the 0-7.5 cm layer. Organic Soils were estimated to lose the greatest quantity of P (24 kg/ha/yr) followed by Podzols (22 kg/ha/yr) and Gleys (17 kg P/ha/yr). Although these numbers were derived from the slope of a linear fit to the data, for the Organic Soils, data was better fitted by a non-linear function (*P loss* = 490ln (*time since development*) – 670; R^2 = 0.80, P<0.001) commensurate with an initially rapid rate of P loss that decreased with time (Figure 3). Therefore a linear fit could overestimate P losses from Organic Soils at later time points. Additionally, it should be noted that while the mass balance shows P is being lost, it does not stipulate where the P is being lost too, which is likely to be a combination of transfer to other parts of the farm by stock, deeper soil layers and to runoff.

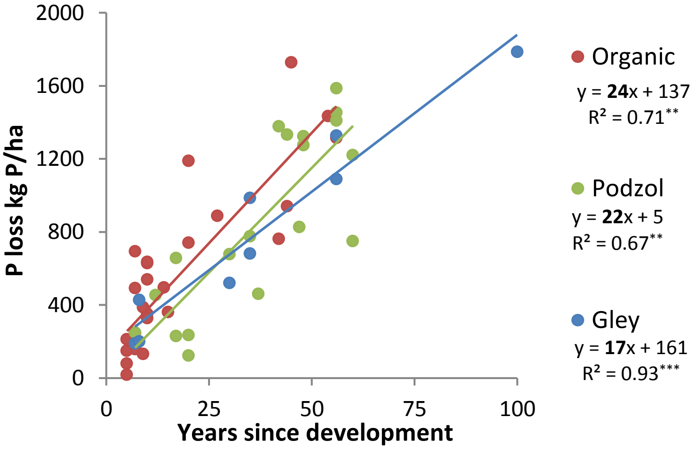

Figure 3. Relationship between P lost via the mass balance from the 0-7.5cm depth of soil and years since development. The slope of this relationship yields an annual loss rate.

Conclusions

Water extractable P, as an indicator for potential P loss in surface runoff, was enriched in those soils with low ASC and/or high Olsen P concentration. Many of these soils in the data set analysed were of the Organic Soil Order that had been recently brought into production. With time since development, WEP concentrations in Organic Soils decreased to reach a near steady state after approximately 25 years. There was no significant decrease in WEP over time for the other Soil Orders. The decrease was attributed to an increase in ASC, BD, and pH and decrease in C concentration. A mass balance confirmed that Organic Soils were losing more P than other soil orders, but also suggested that this decreased with time. The results of this study indicate that P losses from Organic Soils from the coastal Southland catchment sampled are potentially large, but decrease with time since development and that strategies to decrease P loss are important for Organic Soils especially within the first 25 years of development.

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