Phosphorus in Treated Municipal Wastewater irrigated onto NZ-native vegetation

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Executive summary

- Potentially, irrigating Treated Municipal Wastewater (TMW) onto NZ-native vegetation could result in the accumulation of phosphorus (P) in the soil to the point that the soil becomes infertile and excess P degrades local waterways. The Christchurch City Council commissioned the University of Canterbury to determine acceptable levels of P in TMW that is to be applied to NZ-native vegetation.

- An assessment was made using calculations of the likely effects of adding TMW on soil P concentrations and P losses to that could lead to waterway degradation. These results of these calculations were compared with literature reports of the effects of soil P on soil fertility and P-losses.

- Calculations revealed that irrigating 500 mm/yr of TMW containing either 5, 10 or 15 mg/L P would result in P accumulation in the soil. This is because P losses through vegetation removal, leaching, and runoff from TMW-irrigated native vegetation, are negligible compared to the P that is added to the soil.

- Over a 50-year period, the concentrations of soil P in the Pawson Silt Loam and Barry's Soil receiving 500 mm/yr of effluent containing 10 mg/L would increase by 84% and 100%, respectively. Nevertheless, even with these increases, the total average P concentrations in the top 0.3 m would remain within the range of total P concentrations found in NZ's agricultural soils.

- In the aforementioned scenario, Olsen-P, a measure of plant-available P, would also significantly increase in both soils but still remain within ranges considered optimal for a high-fertility soil (the PSL), and within a low-fertility soil (BSL). The increase in Olsen-P may be unfavourable for some NZ-native species, however, there are many other NZ-native species that will thrive under these high-P conditions. This indicates the importance of plant-selection for any treatment system.

- In the aforementioned scenario, there would be an increase in the amount of P-leaching below the top 0.3m of topsoil to around 2.2 kg/ha/yr after 50 years of application. However, most of this P would be retained in the subsoil before it reaches waterways. Given that NZ-native vegetation will decrease surface runoff and soil loss, the increase in P leaching will be more than offset by the reduction of P entering waterways through erosion and overland flow: There is likely to be less P lost under TMW-irrigated NZ-native vegetation than an intensively-grazed pasture.

- Estimations using these calculations indicate that the application of 50 kg P/ha/yr with TMW is unlikely to cause serious soil fertility or environmental issues over a 50-year period. The life of the system could be extended using lower rates of P addition or by periodically harvesting the native vegetation.

Introduction

Treated Municipal Wastewater (TMW) contains environmentally significant concentrations of plant nutrients, including phosphorus (P). While the application of P to soil can improve plant growth (McLaren and Cameron 1996), excess P is can accumulate in soil where it may become toxic to plants (Hawkins et al. 2008). High concentrations of P in soil can increase the chance that this element can enter waterways via runoff, erosion or to a lesser extent, leaching (McDowell and Condron 2004). Elevated levels of P in waterways exacerbate eutrophication, including the uncontrolled growth of aquatic macrophytes and algae (Tilman et al. 2001).

Phosphorus is routinely added to agricultural soil in NZ. Most soils require more P to be added than is removed by plants, because much of the added P becomes immobilized and unavailable for plant uptake (McLaren and Cameron 1996). Measuring the total P in soil is a poor indicator of the P-availability to plants or P that is likely to leach into waterways, because only a fraction of the total P in soil is mobile and available to plants. Plant availability is often indicated by measurements using a mild chemical extractants. In New Zealand and elsewhere, 'Olsen-P' provides good information on the plant-availability of P in a soil (LandcareResearch 2017). Similarly, extractions using calcium chloride ($CaCl_2$), indicate the concentration of P in soil solution, which has the potential to leach through the soil profile (Sanchez-Alcala et al. 2014).

To convert a low-fertility soil, such as a forest soil, into productive pasture, a large application of P, 'capital P', is required. This can be as much as 500 kg P/ha (Dollery 2017). Thereafter, 'maintenance P' is applied, depending on the land use, usually between 5 and 40 kg P/ha/yr (McLaren and Cameron 1996). The application of P from TMW can be higher than that, which would be applied from P fertilisers. For example, the application of 500 mm/yr TMW from the Duvauchelle wastewater treatment plant, which contains an average of 11 mg/kg P(Gutierrez-Gines, McIntyre, et al. 2017) is the equivalent of 55 kg P/ha/yr.

While a significant amount of P that is added to agricultural soil is removed in the produce, the application of P to NZ native vegetation, where no plants are removed, will result in an accumulation of P in the system. This may result in toxicity to plants and or environmental degradation.

This report aims to determine the likely rate of P accumulation, P toxicity, and P mobility, resulting from the irrigation of TMW onto native vegetation on Bank's peninsula.

To assess these aims, the effects of irrigating 500 mm of TMW onto two Bank's Peninsula soils, the Pawson Silt Loam (PSL), 43°45'8.78"S 172°56'35.55"E and Barry's Soil (BSL), 43°44'53.06"S 172°55'41.44"E, also a silt loam, were estimated using mass balance calculations. These calculations used data from the PSL, BSL reported in (Gutierrez-Gines, McIntyre, et al. 2017) as well as other unpublished data from ongoing investigations. It was assumed that the amount of P removed in the NZ native vegetation was negligible. The calculations were run over a simulation period of 50 years. Other parameters used in the calculations are given in the Table.

The calculations assume that there is negligible runoff and erosion under the native vegetation because (a) the TMW would only be irrigated onto gently sloping land (<15°), (b) tree roots stabilize the soil, mitigating soil loss (Robinson et al. 2009), and (c) increase infiltration and preferential flow around the tree roots mitigate overland flow (Knechtenhofer et al. 2003; Sidle et al. 2006).

Table. Parameters used in the mass balance calculations for P application to NZ native vegetation on two soil types on Bank's Peninsula

	Pawson Silt Loam (PSL)	Barry's Soil (BSL)
Effluent P concentration (mg/L)	5, 10 or 15	5, 10 or 15
Effluent application rate (mm/yr)	500	500
P application rate (kg/ha/yr)	25, 50, or 75	25, 50, or 75
[1]Water flux (mm)	800	800
[2]Initial soil P concentration (mg/kg)	1046	599
[3]Olsen-P (mg/kg)	39	9
[4]Water soluble P ($CaCl_2$) (mg/L)	0.18	0.04
[2]Soil density (t/m^3)	1.4	1.4
Simulation depth (m)	0.3	0.3

[1]Estimated from rainfall (922 mm/yr) + TMW irrigation (500 mm/yr) – evapotranspiration (ca. 622 mm/yr)
[2]Measurements from (Gutierrez-Gines, McIntyre, et al. 2017)
[3]Unpublished data, Lincoln University
[4]Estimated from ratios with Olsen-P on similar soils from McDowell and Condron (2004) and Sanchez-Alcala et al. (2014).

Fig. 1 shows the results of these calculations. Under the nominal case of irrigating 500 mm/yr of TMW containing 10 mg/L P, over a 50-year period the total P concentration in the top 0.3 m will increase from 1046 to 1624 mg/kg in the PSL and from 599 to 893 mg/kg in the BSL. Even with this increase, the total concentration at the end of the 50-year period is still well within the range of P concentrations reported for NZ agricultural soils reported by McDowell and Condron (2004) and Reiser et al. (2014). It should be noted that the concentrations calculated here are averages and due to the highly heterogeneous nature of flow pathways in a forested soil (Knechtenhofer et al. 2003), it is likely that there will be localized areas with significantly higher concentrations. Gutierrez-Gines, McIntyre, et al. (2017) reported no significant increases in total soil P in a lysimeter experiment following the application of 2375 mm of TMW containing 11 mg/L P, probably because the total increase in P was within the measurement error and because of heterogeneity in the system.

In the nominal case, the plant-available or 'Olsen P' in these soils is likely to increase from 39 to 61 mg/kg in the PSL and increase from 9 to 14 mg/kg in the BSL. The initial Olsen-P concentration in the PSL is within the range (35-40 mg/kg) recommended by Dairy NZ to maintain high productivity on sedimentary soils (DairyNZ 2018). This is undoubtedly a result of good soil management under previous land use, grazed pasture. In contrast, the BSL, with an initial Olsen-P concentration of 9 mg/L is consistent with non-productive but managed land, in this case a golf course. Even with an increase to 14 mg/kg, the plant-available P would only be sufficient for low P-requiring crops such as for winter wheat (Tang et al. 2009). For pasture, Olsen-P values above 100 are excessive and values are considered 'high' from 50 – 100 (LandcareResearch 2017).

It is likely that the high plant-available P concentration on the PSL would inhibit the growth of some NZ-native species that are adapted to a low-P environment. LandcareResearch (2017) reports that for native vegetation, Olsen-P values of 8-12 mg/kg is considered high and 12 – 15 mg/kg is excessive. However, there are many reports that some NZ-native species can thrive with Olsen-P values manifold higher e.g. Gutierrez-Gines, Robinson, et al. (2017) and Reis et al. (2017). Indeed, 11 species of native plants are thriving on the very same PSL (with an initial Olsen-P of 39 mg/kg), which has received TMW for nearly 3-years (Figure 2).

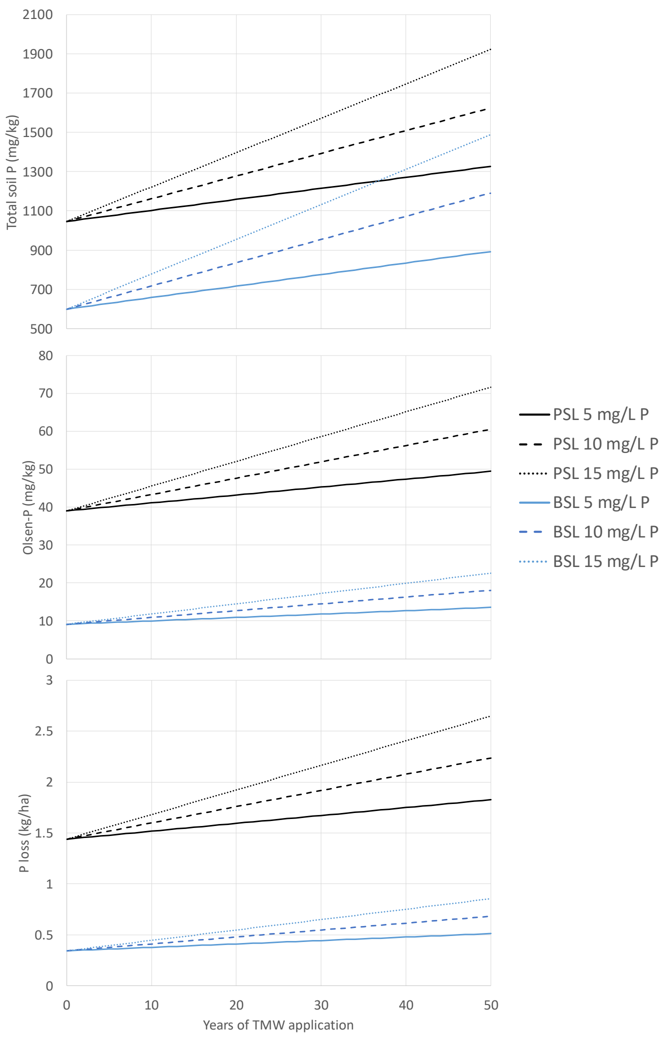

Figure 1.

Calculated phosphorus (P) in the top 0.3m of the Pawson Silt Loam (PSW) and Barry Soil (BSL) under irrigation with TMW at 500 mm/yr with a P concentration in the effluent of 5, 10 or 15 mg/L. The parameters used for the calculations are given in Table 1.

Fig. 1 also shows that irrigating TMW onto native vegetation will result in a significant increase in P leaching from the top 0.3 m of topsoil. This is because of the additional P added to the system in the TMW and the increased water flux through the soil. In the aforementioned scenario, P leaching below the top 0.3m would increase to 2.2 kg/ha/yr in the PSL and to 0.9 kg/ha/yr in the BSL after 50 years. It should be note that, depending on the depth of groundwater, most of this P lost from the top 0.3 m will be retained by the subsoil, which is rich in P-binding oxides of iron and aluminium (McLaren and Cameron 1996). In comparison, the estimated current total P-loss through soil loss from the same area under grazed pasture ranges from 2 – 15 kg/ha/yr, based on soil loss maps (https://statisticsnz.shinyapps.io/soil_erosion/). Under native vegetation irrigated with TMW, significantly less P would be lost through runoff or soil loss compared to a grazed pastureland because the trees increase infiltration and stabilize the soil (Robinson et al. 2009; Sidle et al. 2006). It is therefore likely that irrigating NZ-native vegetation with 500 mm/yr of TMW containing 10 mg/kg P will result in less P-loading on surface waters than a conventional grazed pasture.

Fig. 2. PhD candidate Alexandra Meister and Dr Jacqui Horswell among NZ native vegetation receiving Treated Municipal Wastewater, Pipers Valley Road, Duvauchelle. 12th February 2018.

The calculations indicate that TMW irrigated onto NZ-native vegetation with application P at a rate of 50 kg/ha/yr will result in soil and plant-available P concentrations that are still within the ranges of NZ agricultural soils and that excessive P-leaching is unlikely. While it is likely that some NZ-native species will not tolerate these levels of plant-available P, there are published studies showing that many NZ-native species can tolerate such levels (Gutierrez-Gines, Robinson, et al. 2017; Reis et al. 2017). Lower P application rates will prolong the life of the system, as would periodic removal of some of the vegetation e.g. periodic harvesting of manuka or kanuka to produce high value essential oils.

The application of any element to a system at a rate than is greater than the rate that it is removed is ultimately unsustainable (Mills et al. 2005). If a soil P concentration were reached when a NZ-native ecosystem collapsed or if unacceptable concentrations of P were leaching, then the soil could usefully be converted to high-fertility agricultural soil for pasture or cropping.

Note that this report is based on calculations using soils from the Duvauchelle Golf Course and Pipers Valley Road. Soils from other locations on the peninsula (e.g. Robinson's Valley) may have different initial conditions due to differences in soil use history.

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