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THE LEACHING AND RUNOFF OF NUTRIENTS FROM VINEYARDS

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Abstract

To assess nutrient losses in New Zealand's major viticultural regions, we carried out for New Zealand Winegrowers, a comprehensive and comparative national study of nutrient leaching and runoff. This modelling exercise used detailed weather and soils information with an appropriate set of viticultural practices. We used our mechanistic Soil Plant Atmosphere Simulation Model (SPASMO) to provide these simulations. The SPASMO model has been validated against nutrient loss measurements from drainage fluxmeters in vineyards. We carried out simulations on 89 viticultural soils across New Zealand's six viticultural regions of Gisborne, Hawke's Bay, Martinborough, Marlborough, Nelson and Central Otago. The fertiliser regime we adopted for our modelling was a spring application of di-ammonium phosphate at 25 kg/ha, which corresponds to an annual input of about 5 kg-N/ha and 5.5 kg-P/ha. Viticulture is a parsimonious user of fertiliser. Nationally we found that vineyards leach around 8 kg N-NO_3/ha/y, and they lose 0.25 kg-P/ha/y. Thus viticulture is probably one of the land uses with the lowest nutrient losses. These low numbers provide eco-verification for New Zealand's wines.

Introduction

The leaching of nutrients through the rootzone of primary production systems is having a deleterious effect on the quality of the water in our receiving water bodies. There is a strong public push in New Zealand to maintain, or better still, enhance the water quality of our rivers and lakes. Land management is seen as the cause of decline in the quality of our surface waters (Land and Water Forum 2012).

Meanwhile, consumers and supermarkets are placing increased scrutiny on the metrics of sustainability for the products they buy and sell. Producers who can eco-verify the sustainability of their production system will be able secure eco-premium prices on the shelves of the most discerning of markets, or in top restaurants (Clothier 2015).

The recent National Policy Statement for Freshwater Management (NPS-FW) with national 'bottom lines' for water quality in its National Objectives Framework (NOF) has raised industry concerns about whether certain land uses will be able to comply with impending regulations (Ministry for the Environment, 2014). The NOF specifies 'bottom line' quantitative measures for water quality, such as 6.9 mg N-NO_3/L for nitrogen (N) in rivers, and 0.05 mg P/L for phosphorus (P) in lakes.

Modelling

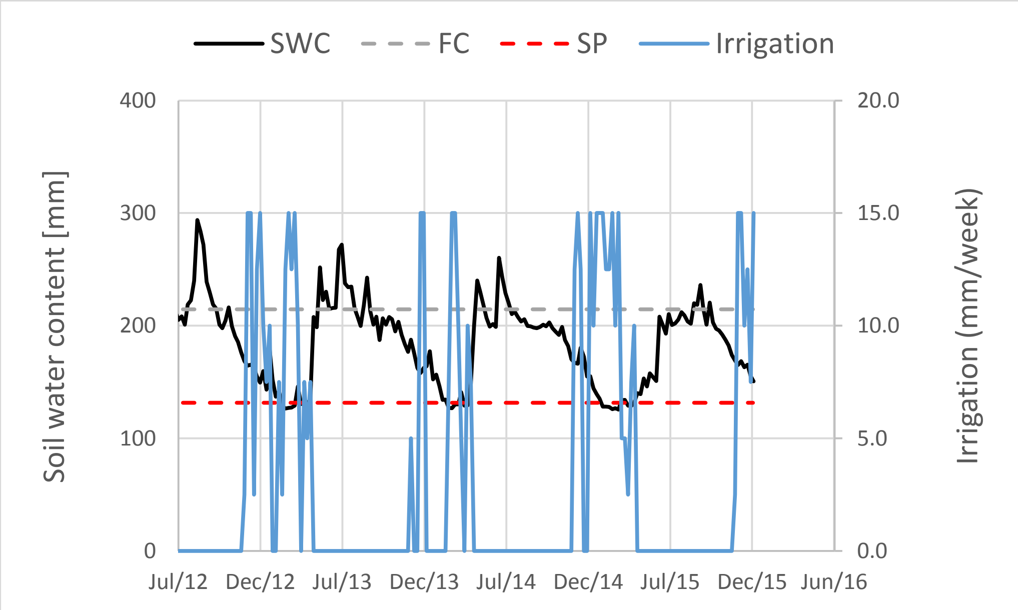
Through a New Zealand Winegrowers project, we have carried out a comprehensive and comparative national study of nutrient leaching and runoff using detailed weather and soils information with an appropriate set of viticultural practices. We have used our mechanistic Soil Plant Atmosphere Simulation Model (SPASMO) to provide these simulations (Green at

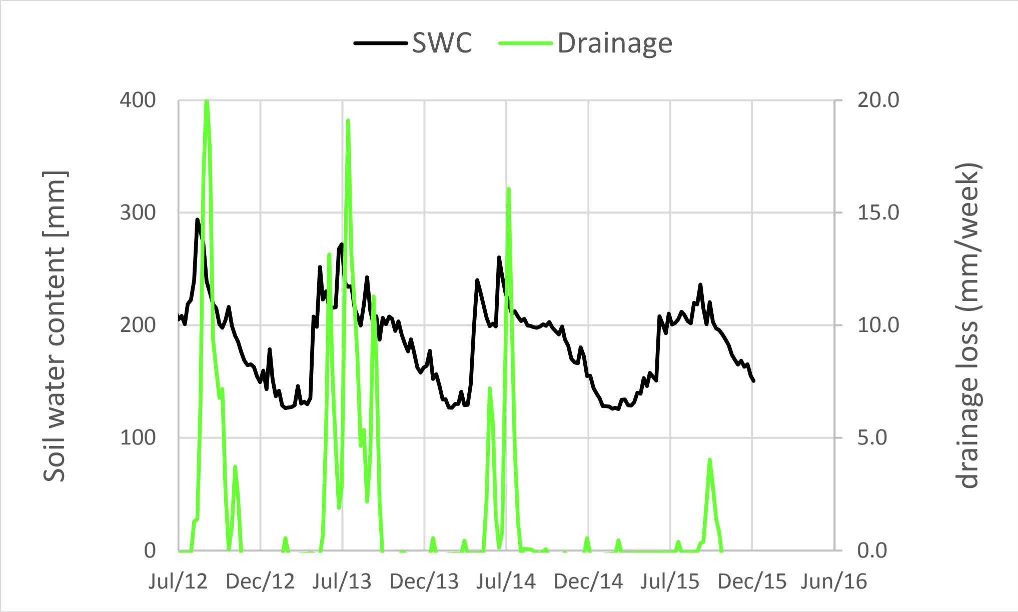
al., 2008). For this project, to assess nutrient losses from New Zealand's major viticultural regions, our model SPASMO was run using a daily time-step based on 44-year-long records of weather.
The fertiliser regime we adopted for our modelling was a spring application of di-ammonium phosphate at 25 kg/ha. This corresponds to an annual input of about 5 kg-N/ha and 5.5 kg-P/ha. This fertiliser regime is standard vineyard practice. Fertiliser use in viticulture is kept to a minimum in order to avoid vegetative vigour.

We first considered the impact of four irrigation scenarios in Marlborough on groundwater recharge and nutrient losses. These were no irrigation, regulated deficit irrigation, managed irrigation and calendar irrigation:

- No irrigation.
- Regulated deficit irrigation, where post-véraison, a soil water deficit of 40% readily available water (RAW) left in the top metre was used as the objective in setting irrigation frequency. The soil water content (SWC) is held at this stress point (SP) post-véraison.
- Managed irrigation, where irrigation was applied whenever the SWC reaches the refill point of 60% of the totally available water (TAW) left.
- Calendar irrigation, where 5 mm of water applied every 3 days, regardless of weather over the period 1 November to 1 April.

The SPASMO-modelled weekly patterns of soil water content (SWC), drainage recharge, plus nitrate and phosphorus losses are shown in Figure 1 for the regulated-deficit irrigation (RDI) scenario of grapes growing on a Wairau silt loam in Marlborough. Here FC is the field capacity and SP the stress point. The model runs on a daily time step, however for ease of interpretation the results in Figure 1 are aggregated to weekly totals.





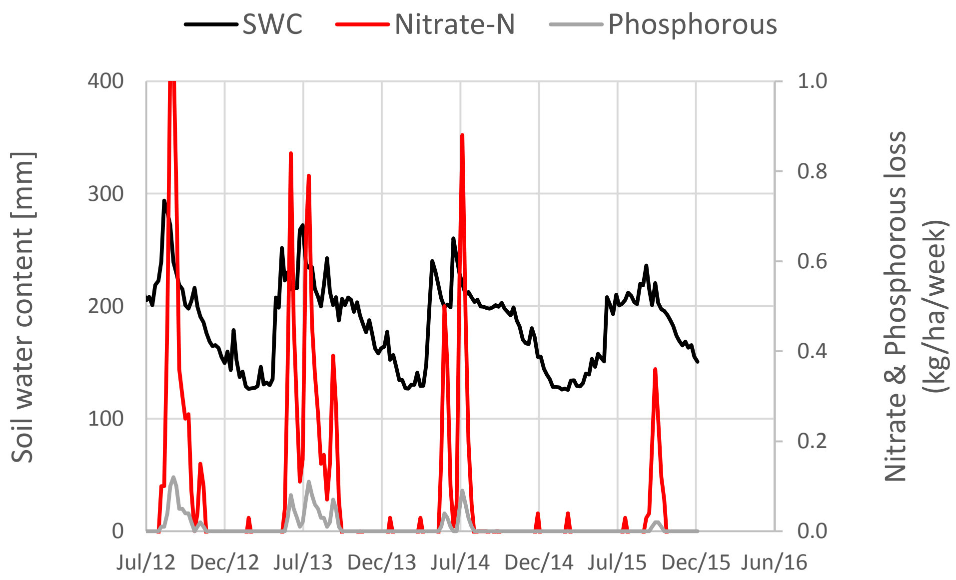


Figure 1. Upper. The weekly pattern of modelled soil water content (SWC) in relation to the soil's field capacity (FC) and stress point (SP) over the window from July 2012 until December 2015. The irrigation scenario (blue) was by regulated deficit. Middle. Along with the weekly pattern of SWC is shown the modelled weekly sequence of drainage recharge (green) 1 m below the rootzone of the grapes. Right. The modelled weekly pattern of nitrate leaching (red) and phosphorus losses (blue) from the rootzone, along with the weekly trend in SWC. The soil here is the Wairau silt loam.

In the top graph of Figure 1 can be seen the weekly pattern of SWC and irrigation under this modelled RDI regime. The median annual irrigation requirement for RDI is 42.5 mm, although in 20% of the years this will exceed 88.5 mm. The median monthly statistics are somewhat 'misleading' because of the high variability in irrigation requirements due to irregular rainfall. Over the 44-year period for the month of January, RDI was not required in 26 of the years, so the median value is indeed zero. On average, however, the irrigation season for RDI begins in November and ends in April.

The middle graph of Figure 1 shows (again) the weekly pattern SWC, but now with the modelled weekly drainage below the base of the 1 m rootzone. This drainage serves as groundwater recharge. The median groundwater recharge is 112.9 mm. The rainfall here is 679 mm, so some 17% of rainfall serves to recharge the underlying groundwater aquifers. The droughts of 2013/14 and 2014/15 can be seen to have led to much reduced drainage.

In the bottom graph of Figure 1 we show (yet again) the SWC, but now along with the weekly losses of nitrate and phosphorus. Under RDI, for the Wairau silt loam, the median value for nitrate loss is 13.5 kg N-NO_3/ha/y, although in 20% of the years it will exceed 21.3 kg N-NO_3/ha/y. Leaching losses are confined to the winter period from July through to November. The average phosphorus loss by both leaching of DRP and runoff of soil-bound P was modelled to be 0.14 kg-P/ha/y. The losses of N and P during the droughts of 2013/14 and 2014/15 are much reduced.

Irrigation
We have shown through modelling for the Wairau silt loam that for most viticultural irrigation regimes, except for calendar irrigation which applies an excessive amount of water, there would be sustainable consumption of water by irrigation abstraction, drainage recharge, and nutrient losses (Figure 2). For the most likely irrigation regimes of no irrigation, regulated-deficit irrigation and managed irrigation, the nitrate loads are between 10 and 15 kg N-NO_3/ha/y, and the phosphorus losses are between 0.1 and 0.2 kg P/ha/y. The lack of difference in nitrate leaching between irrigation regimes highlights that soil-water dynamics play a lesser role in controlling leaching, than do soil-nitrogen dynamics. Irrigation does affect drainage recharge of the underlying aquifers, but to a much lesser extent the leaching of nitrate.

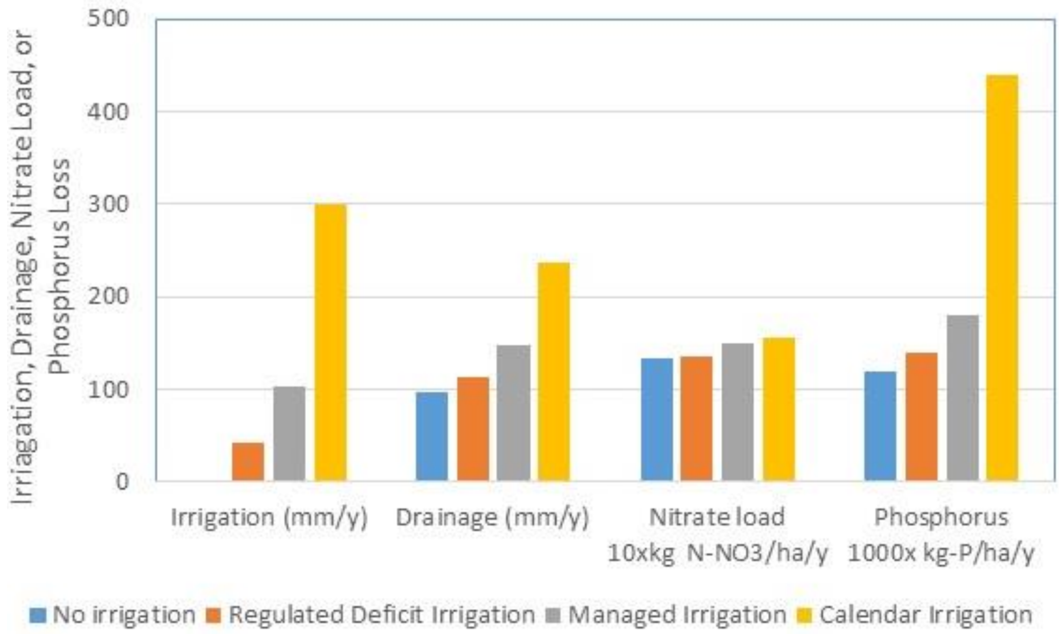


Figure 2. The long-tern averages for irrigation requirements (mm/y), drainage recharge (mm/y), nitrate load (10xkg N-NO_3/ha/y) and phosphorus losses (1000xkg-P/ha/y) for the four irrigation scenarios modelled for grapes growing on a Wairau silt loam in Marlborough.

Regional Assessments
We next carried out SPASMO simulations across the six viticultural regions of New Zealand comprising Gisborne, Hawke’s Bay, Martinborough, Marlborough, Nelson and Central

Otago. For this national study we only considered the regulated deficit irrigation scenario (RDI). A total of 89 viticultural soil-types were used across these six regions. Deficit irrigation is likely the most common irrigation practice.

For this regional comparison, within all but the Gisborne region we could geo-reference viticultural production to specific soil types. Thus we could provide an areally weighted average for each region. To obtain a representative average for the whole of New Zealand, we weighted the regional averages by the respective areas of grapes grown in the six regions. This then covers 94.9% of the grapes grown in New Zealand. These summary results are presented in Table 1.

Whereas irrigation regime had only a minor effect on nitrate leaching, the role of the soil, and in particular its carbon to nitrogen ratio (C:N), plays a dominant role in determining nitrate leaching.

Table 1. Summary of the regional average loadings and concentrations of nitrate and phosphorus losses from vineyards across six viticultural regions of New Zealand. The irrigation regime was considered to be by regulated deficit irrigation (RDI). Within regions, except for Gisborne, the mean average losses are weighted by the areas of the specific soil types under viticulture, and nationally the averages are weighted by the fractional regional areas under vineyards in New Zealand for 2016.

Region	Number of soils	Nitrate Load [1] kg NO_3-N/ha/y	Nitrate Concentration mg/L	Phosphorus Load kg-P/ha/y	Phosphorus Concentration mg/L
Gisborne[2]	10	8.7	3.1	0.26	0.09
Hawke's Bay	15	6.2	4.4	0.51	0.22
Martinborough	10	14.0	8.0	0.09	0.04
Marlborough	31	9.2	8.5	0.25	0.18
Nelson	12	9.0	2.8	0.03	0.01
Central Otago	11	1.2	23.1	0.09	0.07
National[3]	**89**	**8.0**	**7.9[4]**	**0.25**	**0.16[4]**

1 Areally-weighted mean by viticultural soil type (maximum, minimum)
2 Simple average, no areal weighting
3 Areally weighted values for soils in all regions, except Gisborne, and the national average is weighted by the regional vineyard areas (Table 1)
4 The NOF of the NPS-FW has national "bottom lines" for rivers of NO_3 at 6.9 mg/L, and P in lakes at 0.05 mg/L

The national average load of nitrate leaving the rootzones of New Zealand's vineyards is just 8 kg N-NO_3/ha/y, and the average concentration is 7.9 mg/L. This concentration does however exceed the median national 'bottom line' for rivers in the NOF of the NPS-FW of 6.9 mg/L. The average loading of phosphorus is 0.25 kg-P/ha/y, and the average concentration of the loss is 0.16 mg/L. This concentration exceeds the median 'bottom line' for P in lakes in the NOF of the NPS-FW of 0.05 mg/L.

Whereas our results here provide an assessment of the impact of viticulture on the losses of nutrients from the base of the rootzone of grapes, or runoff from the surface, the NPS-FW demands that Regional Councils develop regulations by 2025 to ensure compliance with national 'bottom lines' of water quality in the receiving bodies of our lakes and rivers. Thus the challenge is to understand the attenuation, assimilation and dilution that occurs between the bottom of the rootzone and the receiving water bodies.

Green et al (2014) carried out a study that linked rootzone leachate with receiving water quality that is being funded by the Marlborough District Council (MDC). An array of tension drainage fluxmeters (DFM) was set-up during 2012 in a vineyard on Giffords Road near Renwick in Marlborough. These have recorded drainage and nitrate leaching since then. As part of the National Groundwater Monitoring Programme, the MDC takes monthly water samples from the region's wells. The pattern of nitrate concentrations measured 'upstream' in the DFMs was compared with the groundwater monitoring values at one well some 2.4 km away from the vineyard site.

It was found by Green et al. (2014) that the pattern of nitrate concentration in the bore lagged by 185 days the pattern of rootzone leaching, and more importantly there was a dilution by 90%. The concentration in the groundwater was just 7% of the 'bottom line' for nitrate in rivers in the NOF. On average, the receiving water here even meets the stringent ANZECC 'trigger-value' of 0.444 mg/L. Thus although the leachate concentrations at the base of the rootzone might exceed the NOF of the NPS-FW, and the ANZECC trigger-value, geohydrological attenuations and dilution processes enable the receiving waters to meet national 'bottom line' standards.

Plan Change 6

Our modelling results can also be used to assess the implications of the decisions by a recent Board of Inquiry into the Tukituki catchment. Beginning in 2008, the Hawke's Bay Regional Council (HBRC) initiated the development of Plan Change 6 (PC6) for the Tukituki catchment. In May 2013, PC6 was notified and *inter alia* sought to:

- Implement and give effect to the 2011 NPS-FW
- Address specific water allocation and water quality issues
- Set water quality limits and targets.

The HBRC sought an 'integrated decision-making' approach by asking PC6 to be 'called in' to be heard by a single Board of Inquiry. The Board adopted a 'natural capital' based approach, following the Horizons One Plan (Clothier et al., 2007), by using the Land Use Capability (LUC) class system for the allocation of nitrate discharge allowances. Given the SPASMO modelling we have now carried out here, we can examine how the soils across the wider Hawke's Bay might meet any regulations developed under PC6 for just the Tukituki. We recognise that there is not a 1:1 correspondence between soil type, which we have used here for our detailed modelling, and the broader classification of LUC. But our results can provide guidance as to which viticultural zones will comply with PC6.

We found that the leaching load from 48.6% of the viticultural soils in the Hawke's Bay would meet the leaching limit for all eight LUC classes. Another 36.4% of viticultural soils would meet compliance up to Class VII. A specific problem that we were asked to address related to the Gimblett Gravels which are LUC VII. The Gimblett Gravels are modelled as the Ngatarawa sandy loam. In PC6, the leaching limit for LUC Class VII is 11.6 kg N-NO_3/ha/y. Our modelled annual average for the Ngatarawa sandy loam is just 1.6 kg N-NO_3/ha/y. So this would provide viticulture with the eco-verification it needs to meet the conditions of PC6. It is stressed, nonetheless, that this compliance relates to the fertiliser, grazing and stock management conditions we have simulated.

Conclusions

Nationally, across 89 soils in 6 viticultural regions, we have found that vineyards are predicted to leach 8 kg N-NO_3/ha/y and to lose 0.25 kg-P/ha/y. Thus viticulture is likely one of the land uses with the lowest nutrient losses. These low numbers provide eco-verification for New Zealand's wines (Clothier 2015).

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