IS THE GREY-WATER FOOTPRINT HELPFUL FOR UNDERSTANDING THE IMPACT OF PRIMARY PRODUCTION ON WATER QUALITY?

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Abstract

Globally agricultural production generates a significant proportion of the anthropogenic environmental impacts on water resources. Because of agriculture's large water usage, and its contribution as a non-point source of agrichemical emissions into freshwater, agricultural production is considered central to future attempts for overcoming the global stress on water resources. Locally, agriculture is the dominant land use in New Zealand, and it has the most widespread impacts on freshwater quality and quantity. The concept of grey-water footprint (grey-WF) has been proposed as a metric that indicates impacts of the agricultural production systems on the quality of water resources. It is calculated as the volume of freshwater that is required to 'dilute' a pollutant so that its concentration meets the prevailing water quality standards.

The impacts of wine-grape production on the quality of water resources were assessed for two regions in New Zealand: Marlborough and Gisborne. In our assessment, the vineyards were on 29 different soil types spread across 19 climatic regions, and approximately 12,600 ha under grapes were considered across both the regions. Nitrate-nitrogen (NO_3-N) was considered as the major pollutant. The soil-water dynamics and nitrate leaching in the vineyards were modelled using the Soil Plant Atmosphere System Model (SPASMO). The grey-WF was 40 and 188 L/kg of harvested grapes from Marlborough and Gisborne, respectively. However, the average concentration of NO_3-N in the leachate was well below the drinking water standard of 11.3 mg NO_3-N /L, being just 5.01mg NO_3-N /L and 8.7 mg NO_3-N /L for Marlborough and Gisborne. The grey-WF as a measure of the impact on water quality could be used to make comparisons between products from different regions if the same standards are used. However, the absolute value is less meaningful to understand the local impacts. Furthermore, from a resource management perspective, use of the grey-WF in setting limits of pollutant loads in regulatory policy decisions is not straightforward.

Key words: water quality; nitrate leaching; groundwater; wine-grape; vineyards

Introduction

Globally, agriculture has a significant impact on water quality. It contributes to non-point source water pollution through nutrients, pesticides and other contaminants. Agricultural nutrient losses are a major contributor to water pollution around the world, and in New Zealand in particular (Marsh, 2012). Agriculture plays a prime role in New Zealand's economy. As New Zealand's agriculture sector expands, more pressure is being put on its ecological infrastructures. Water pollution is now considered to be one of the most important environmental issues facing New Zealand (Marsh, 2012). Intensive agricultural production has significantly influenced the quality of surface and groundwater resources. The challenge for farmers is to maintain the benefits of irrigation and agrichemical use, whilst minimising the adverse effects on the receiving water resources.

The pollutants that come from diffuse, non-point sources are much more difficult to quantify, as compared to point-source discharges. Therefore, the impact of primary production on the quality of receiving water resources is challenging to quantify, and contentious to manage. The grey-water footprint is proposed as an indicator of the impacts of land use on the quality of fresh water resources. It is calculated as the volume of freshwater that is required to ‘assimilate’ the load of pollutants so that they are within guideline values based on natural background concentrations and the appropriate water quality standards (Hoekstra et al., 2011).

Due to the difficulty of measuring nitrate leaching and the contamination of water resources, most of the grey-water footprint calculations have been based on the simple assumption that on average about 10% of the nitrogen applied in fertilizer is lost through leaching (Chapagain et al., 2006). This is a very approximate estimation which obviously excludes factors such as; soil types, agricultural practices, local soil hydrology and the interaction between different chemicals in the soil. The objective of this study was to quantify the impact of wine-grape production on water resources using the concept of the grey water footprint considering different soil types and weather conditions. We also assess the load and the concentration of the pollutants that leave the root zone of vineyards.

Methods

Area considered, regional dynamics, climate and soil variability

Two major, and contrasting, grape growing regions in New Zealand were considered: Marlborough and Gisborne. Marlborough is the largest wine- grape region which accounts for 57% of the vineyard area in New Zealand while Gisborne is the third largest and its vineyards cover 6% at present (Annual Report, 2012; Hayward and Lewis, 2008).

The two regions are different in terms of climate, water resource availability and soil types. The climate is highly variable across Marlborough, and the soil types are quite variable within both the regions. The average rainfall in the Marlborough region was 620mm/y and that of Gisborne was 1029 mm/y over the 38-year period from 1972 to 2010 (NIWA, 2012). In Marlborough, all the vineyards were irrigated with water sourced from groundwater resources, while Gisborne vineyards were not irrigated. In this assessment, the vineyards were on 29 different soil types spread across 19 weather zones. There were approximately 12,600 ha under grapes across both the regions.

Modelling water and solute dynamics of vineyards

The soil-water dynamics and solute transport in the vineyards were assessed using the Soil Plant Atmosphere System Model (SPASMO) (Green and Clothier, 1999; Green et al., 1999). This is a mechanistic model considers water, solute (e.g. nitrogen and phosphorus), and pesticide transport through a one-dimensional soil profile to the base of the root zone. The SPASMO model includes components that predict the carbon and nitrogen budgets of the soil, which enable calculation of plant nutrient uptake, plus the various exchange and transformation processes that occur in the soil and aerial environment, along with the recycling of nutrients and organic material to the soil biomass, plus the addition of surface-applied fertilizer and/or effluent to the land (Green et al., 2008). This model has been validated for a range of New Zealand soils under various land uses across a wide range of climatic conditions and management practices (Green and Clothier, 1999; Green and Clothier, 1995; Green et al., 1999; Green et al., 2008).

We used weather data (NIWA, 2012) for a 38-year period (1972-2010) to simulate soil-water dynamics and grape production in the regions using SPASMO, so as to explore the range in annual values for the components of the water-balance. The model used local climate data to simulate the water-balance for 29 different soil types within the two regions. Climate data were sourced from the Virtual Climate Network Stations (VCNS) of the National Institute of Water and Atmospheric Research (NIWA), New Zealand (NIWA, 2012). The soil physical and hydraulic properties were deduced using data from the New Zealand National Soils Database (NSD, 2012).

Quantifying the grey-water footprint

As most of the grape-growing areas in both regions are on flat to undulating terrain, potential contamination of surface waters by runoff of agrichemicals was considered to be minimal. Therefore, we considered only the pollution of the groundwater underlying the vineyards in the assessment of impacts on water quality. Nitrate-nitrogen (NO_3-N) was considered the dominant pollutant leaving the root zone of vineyards (Herath et al., 2013).

The grey-WF was calculated as defined by Hoekstra et al. (2011). It is the volume of freshwater that is required to dilute a pollutant so that its concentration meets the prevailing water quality standards (Eq. 1).

$$WF_{Grey} = \left[L / \left(C_m - C_n \right) \right] / Y \qquad \textbf{(Eq. 1)}$$

Here, WF_{Grey} is the freshwater required [L/kg of grapes] to 'dilute' the runoff and leachate down to an accepted water quality standard, L is the net-load of pollutants from the system [mg/ha], C_n is the natural concentration [mg/L] of the pollutant in the receiving water body, and C_m is the maximum acceptable concentration [mg/L] for the pollutant given by the local and appropriate water quality standard. Here, Y is the grape yield [kg/ha/year].

In our assessment, we have used New Zealand's drinking water standard of 11.3mg NO_3-N/L (MoH, 2008) for the C_m. For the background concentration C_b, we used 0.31mg NO_3-N/L for the Marlborough region, which was the average NO_3-N concentration measured in the regional groundwater over the past five-year period (Davidson and Wilson, 2011). For the Gisborne we used 1.7mg/L, which is the national median concentration of NO_3-N for New Zealand groundwaters during 1995-2008 (MfE, 2009). The natural concentration C_n is the NO_3-N concentration in the water body if there has not been any human intervention (Hoekstra et al., 2011). We assumed this to be zero for New Zealand's groundwaters.

Results and Discussion

The grey-WF showed a large variation between the different soil types and weather zones of both the regions (Figures 1 and 2). The weighted average grey-WF for the Gisborne region was 188L/kg, which was higher than that of the Marlborough region, at 41L/kg. We investigated this further and found that there was no significant difference in relation to nitrogen fertilizer application, or other amendments. But rather the Gisborne soils have a higher N-mineralization rate as a result of the higher soil organic matter contents (Pullar, 1962; Rae and Tozer, 1990). High rainfall and consequently greater drainage also contributed to higher leaching of NO_3-N in the Gisborne region.

The outcome of the grey-WF assessment highly depend on the different water-quality standards and the natural concentrations used (Deurer et al., 2011; Hoekstra et al., 2011). Here, we used New Zealand's drinking water quality standards for NO_3-N considering groundwater as the resource.

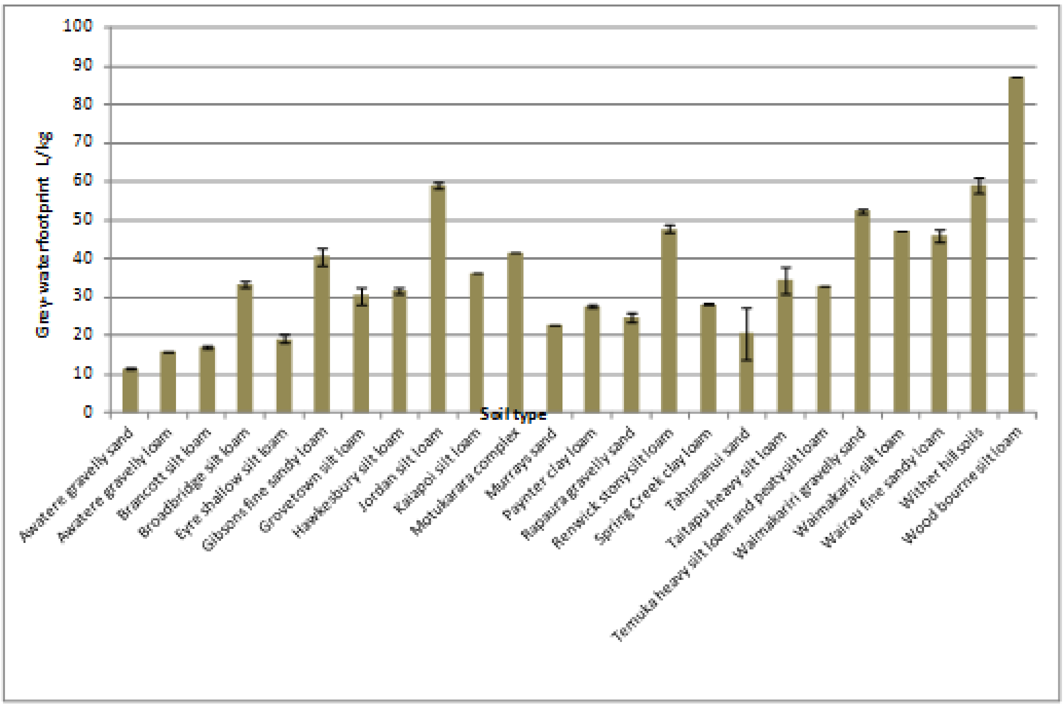

Figure 1. Grey-water footprint as calculated by considering the freshwater required to dilute the leached nitrate down to the New Zealand drinking water standard of 11.3mgNO_3-N/L under the different soil types and local weather zones of the Marlborough region. The bars reflect the variability, mainly induced by the local climatic differences (as presented in Herath et al., 2013).

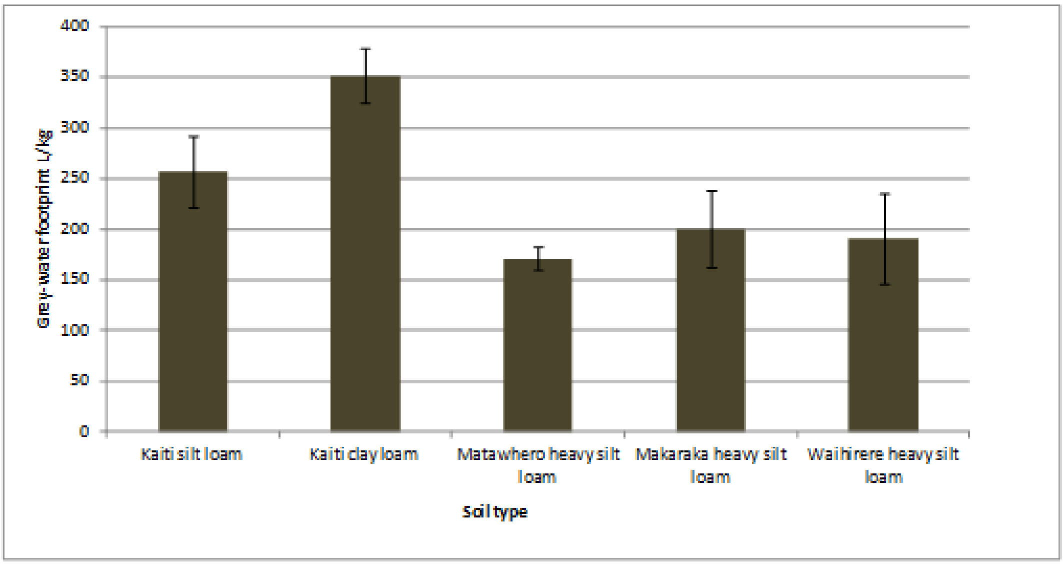

Figure 2. Grey-water footprint as calculated by considering the freshwater required to dilute the leached nitrate down to the New Zealand drinking water standard of 11.3mgNO_3-N/L under the different soil types and local weather zones of the Gisborne region. The bars reflect the variability due to local climate (as presented in Herath et al., 2013).

The weighted average concentration of NO_3-N in the drainage was 5.01mg/L in Marlborough, but with a high variability ranging from 0.51 to 17.9 mg/L for different soil types. For the Gisborne region this was 8.7 mg/L, with a range from 6.9 to 17 mg/L. On a regional average basis, the NO_3-N concentration in the drainage was within the critical level for the drinking water standard of 11.3 mg/L (MoH, 2008).

This method of quantifying grey-WF as the impact on water quality could be used to make comparisons between products and regions when the same water quality standards are used. However, from a resource management perspective, it is doubtful if this grey-WF provides sufficient information for setting limits for pollutant loads in regulatory policy or judicial proceedings. The loading rates and average concentration of NO_3-N in the drainage from vineyards are likely to be more useful for these purposes. Based on the modeling results, we predicted weighted average loading rates as 4.9 and 29.3 kg of NO_3-N/ha/y for the Marlborough and Gisborne regions, respectively. However, the pollutant loading need to be considered together with that of other land uses for it to be meaningful and useful for policy implications.

The variability found here indicates the importance of considering the water quality issues at the local scale. The loading rates and concentrations both need to be considered, together with geohydrological characteristics of the local aquifers, for their volumetric flow rates might well provide sufficient dilution of these loadings.

Conclusion

The grey-WF as a measure of the impact on water quality can be used to make comparisons between products from different regions if same categories of water quality standards are used. However, the use of absolute value is less meaningful for understanding local impacts. From water resource management perspective, the use of the grey-WF for setting limits for nutrient load in regulatory policy decisions is not straight forward.

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References

Annual Report (2012). "New Zealand Wine ", Wine Growers' Annual Report. <nzwine.com/info-centre/> (accessed 10.10. 2012).

Chapagain, A. K., Hoekstra, A. Y., Savenije, H. H. G., and Gautam, R.2006 The water footprint of cotton consumption: an assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries, Ecol. Econ., **60(1)**, 186–203.

Deurer, M., Green, S. R., Clothier, B. E., and Mowat, A. (2011). Can product water footprints indicate the hydrological impact of primary production? A case study of New Zealand kiwifruit. *Journal of hydrology* **408**, 246-256.

Green, S., and Clothier, B. (1999). The root zone dynamics of water uptake by a mature apple tree. *Plant and Soil* **206**, 61-77.

Green, S. R., and Clothier, B. E. (1995). Root Water-Uptake by Kiwifruit Vines Following Partial Wetting of the Root-Zone. *Plant and Soil* **173**, 317-328.

Green, S. R., Clothier, B. E., Mills, T. M., and Millar, A. (1999). Risk assessment of the irrigation requirements of field crops in a maritime climate. *Journal of Crop Production* **2**, 353-377.

Green, S. R, Clothier, B. E., van den Dijssel, C., Deurer, M., and Davidson, P. (2008). Measurement and modelling the stress response of grapevines to soil-water deficits in their rootzones. Chapter 12, In Soil Science Society America Monograph “Modeling the response of crops to limited water: Recent advances in understanding and modeling water stress effects on plant growth processes”, L. Ahuja et al.[Eds], pp 357-386.

Hayward, D., and Lewis, N. (2008). Regional dynamics in the globalising wine industry: the case of Marlborough, New Zealand. *Geographical Journal* **174**, 124-137.

Herath, I., Green, S., Singh, R., Horne, D., van der Zijpp, S., and Clothier, B. (2013). Water footprinting of agricultural products: a hydrological assessment for the water footprint of New Zealand's wines. *Journal of Cleaner Production*, **41**: 232-243.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., and Mekonnen, M. M. (2011). "The Water Footprint Assessment Manual: Setting the Global Standard.," Water Footprint Network. Earthscan Publishing, London, UK.

Marsh, D. (2012). Water resource management in New Zealand: Jobs or algal blooms? *Journal of environmental management* **109**, 33-42.

MfE (2009). Groundwater Quality in New Zealand. State and Trends 1995-2008. Ministry for the Environment, Wellington, New Zealand.

MoH (2008). Drinking-water Standards for New Zealand 2005 (Revised 2008). Ministry of Health. Wellington. New Zealand. ISBN 978-0-478-31810-4 (online).

NIWA (2012). The National Institute of Water and Atmospheric Research, New Zealand (The National Climate Database). <www.cliflo.niwa.co.nz/> (accessed 05.05.2012).

NSD (2012). National Soils Database. New Zealand Land Resource Inventory. Landcare Research, New Zealand. <http://lris.scinfo.org.nz/#> (accessed 12.05.2012).

NZWA (2011). New Zealand Wine Report 2011. Wine Annual New Zealand. NZ1104.<www.nzwine.com> (accessed 08.03.2012).

Pullar, W. A. (1962). "Soils and Agriculture of Gisborne Plains," New Zealand Department of Scientific and Industrial Research, New Zealand.

Rae, S. N., and Tozer, C. G., eds. (1990). "Water and Soil Resources of the Wairau. Volume three; Land and Soil Resources." Nelson-Marlborough Regional Council, New Zealand.