Water Footprinting: Impacts of Potato Production on Water Resources

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Abstract

Agriculture has widespread impacts on quantity and quality of water resources. The water footprint (WF) is a metric that quantifies the environmental impacts related to water use. Impacts of rain-fed potato production in the Manawatu Region of New Zealand were assessed using the hydrological water-balance method of water footprinting. Hydrological components of this cropping system were quantified using a model validated with field measurements including the changing soil-water content (green water) and drainage that recharges groundwater (blue water). The impact of potato cultivation on soil water store was negligible. Potato production was found to be contributed to recharge ground water at the rate of 72 L/kg of potato harvested. Therefore, this production system has no deleterious impact on quantity of water resources. However, concentration of nitrate in the drainage was found to be at the limit for drinking water in New Zealand which is 11.3 mg of NO_3-N/L. The potential options through fertilizer management to reduce these impacts were identified. These were found to improve the system reducing the impacts. Water footprint, therefore, is a useful metric that quantifies the impact of agricultural water use on water resources.

Key words: Groundwater, Grey water, Hydrology, Impacts

Introduction

Protecting and sustaining global water-resources is one of the most challenging issues facing the world. Future food security is threatened by the continued increase in demand for water. Agriculture is, by far, the largest consumer of global freshwater, with irrigation accounting for more than 70% of water withdrawals. Crop development programmes in recent years have led to highly productive cultivars that require intensive management along with fertilizers and other agrichemicals, plus irrigation. Drainage from such highly productive agricultural lands is increasingly being perceived as a major contributor to off-site environmental impacts.

Water footprinting is a method that can be used to understand the environmental impacts related to water use and water-borne emissions. In water footprinting, three water colours are distinguished: blue, green and grey . The 'blue water' refers to the surface and/or groundwater used by the production system. The 'green water' refers to the rain water stored in the soil and used by plants. The 'grey water' indicates water pollution due to leaching and runoff of agrichemicals from the production system. Among the different methods that have been proposed for water footprinting, the hydrological water-balance method has shown to provide a better understanding of the local hydrological impact of agricultural production systems . The main objective of this study was to assess the impact of a commercial potato production system on water resources in the Manawatu Region in New Zealand.

Materials and Methods

The impacts on local water resources due to rain-fed potato cultivation in the Manawatu region of New Zealand were assessed using the hydrological water-balance method of WF for the year 2011/12. The soil type was Manawatu sandy loam (Dystric Fluventic

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Eutrochrept). Impacts were assessed by considering the two main water resources: the groundwater of the blue-water resource; and the soil-moisture store of the green-water resource. The net uses of these two resources are considered here as the blue and green-water footprints, respectively.

Tension fluxmeters were used to measure drainage under the root zone. Drainage volume was measured, and sub-samples were analysed for the nitrate-N and ammonium-N concentrations using a Foss FIAStar 5000 flow injection analyzer (Foss Tecator AB, Höganäs, Sweden). The soil-water content was measured using eight, three-wire Time Domain Reflectometer (TDR) probes of 30 cm length. The green-WF was quantified as being the difference in the stored soil water content in the soil profile between the start and the end of the season. The field measurements of soil water content and drainage were combined with Soil Plant Atmosphere System Model (SPASMO) to simulate the soil-water dynamics and solute transport by considering a 40-year period (1972 to 2012) of weather data. So that calculated WF would not be biased towards any particular year, and would provide the stochastics associated with the average results.

The impact on water quality was assessed using the grey-WF being the volume of freshwater needed to 'dilute' the nitrate reaching the blue-water resource to an acceptable water quality standard (Eq. 1).

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

Here, WF_{Grey} [L/kg of potatoes], is the freshwater required to 'dilute' the runoff and leachate to an accepted water quality standard, L is the net-load of pollutants from the system [mg-NO_3-N/ha], C_m is the maximum acceptable concentration of nitrate [mg-NO_3-N/L] given by the local authorities. The natural concentration C_n is the NO_3-N concentration in the receiving water body as if there has been no human intervention . Here, Y is the marketable potato yield [kg/ha]. The load of nitrate (kg NO_3-N/ha) was quantified by multiplying the drainage volume by concentration of NO_3-N in the drainage.

Results and Discussion

The impact on the quantity of water resources: blue and green water footprints

The soil water contents simulated by the SPASMO model showed good agreement with the field measurements using TDR (Figure 1). The measurement and modelling results showed the annual change in soil-water content was negligible, since in the profile soil moisture content is returned to field capacity by the winter rains. Therefore, the impact of green-water consumption, by the crop, on the green-water resource is insignificant.

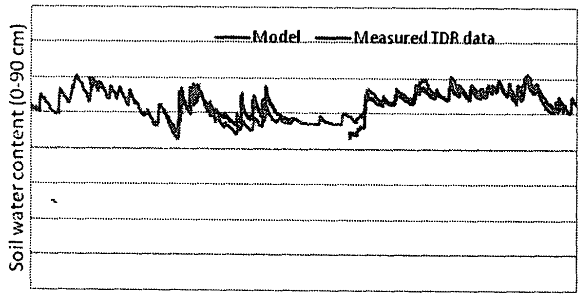

Figure 1. Soil water content stored in the top 90 cm of the soil profile as measured using the mean of eight Time Domain Reflectometry (TDR) probes (red) along with the prediction using SPASMO model (blue).

The measurements of drainage using fluxmeters were high during the 2011/12 season. This is mainly because this season was wetter than the average year. The modelled average drainage of 245 mm/y, and the predicted yield of 44 tonne/ha were used to calculate blue WF. The blue WF was negative because no groundwater was extracted for the cultivation, and rather there was net recharge of 72 L/kg. Therefore, the blue-WF is -72 L/kg which indicates that this potato cultivation has no deleterious impact on the quantity of water resources.

The impact on the quality of water resources: the grey water footprint

Since the ammonium-N concentrations in the drainage were found to be negligible, the grey-WF was attributed only to NO_3-N. By using Eq. 1, the grey-WF was quantified as 55.9 L/kg. For C_m New Zealand drinking water standard of 11.3 mg NO_3-N/L was used. The natural concentration C_n was assumed to be zero. The load, L used here was 27.8 kg of NO_3-N/ha as predicted by the model. The average concentration of NO_3-N in the drainage was 11.3 mg /L which is exactly the drinking water standard. This indicates current practice has some adverse impact on the quality of the receiving groundwater resources.

Reducing water footprints

The main impact of the studied system on water resources was due to leaching of nitrate to groundwater resource. According to our measurements, 71 % of leached NO_3-N occurred during the first 30 days after planting, and 90% occurred during the first 60 days. This is mainly because of the low plant-nitrogen demand during this period and fertilizer applied at the time of planting.

To identify possible options to reduce the grey WF, three fertilizer application scenarios, together with the current practice, were considered. The Early application was at the time of planting, Splitx2 was half applied at planting and the rest was at ridging 28 days after planting (DAP). Splitx3 was each 1/3 of fertilizer applied at planting, 28 days, and at mounding at 55 DAP. The Late application was once at 55 DAP. For all the scenarios, the amount of fertilizer used was 120 kg N/ha, in which 68 kg/ha was in the form of NH_4^+ and 52 kg/ha was NO_3^-. The model prediction showed that the Split applications and Late application of N fertilizer decreased the grey-WF. The grey WF reduced to 50.6, 50.9 and 48.9 L/kg with the Splitx 2, Splitx 3 and Late applications, respectively. Potato yield would not be compromised. Therefore, managing fertilizer with these split applications is an effective and viable option to reduce the impact on the water quality, but will depend on the ease and cost of extra application of fertilizer. The choice of the dates for the splits corresponds to existing trafficking events, namely ridging (28 DAP) and mounding (55 DAP), so that there would be no additional costs of the tractor usage for the applications.

The measurements and modelling indicate that this potato production system has no deleterious impact on water resources in terms of quantity and contributes to recharge of ground water at the rate of 72 L/kg of potato harvested. However, the average concentration of NO_3-N in the drainage was 11.3 mg /L which is exactly the limit of drinking water standard. The modelling of different fertilizer application scenarios indicated that splitting N rate into two or three applications, or having a late application at 55 days after planting, would reduce the leaching of nitrate, shrink the grey-WF and lower the nitrate loading. Water footprint, therefore, is a useful metric that quantifies the impact of water use on water resources. It can also be used to identify improvement options to reduce those impacts, if right protocols are used.

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