Journal of Cleaner Production xxx (2014) 1–9

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Quantifying and reducing the water footprint of rain-fed potato production, part I: measuring the net use of blue and green water

Indika Herath [a, b, c, *], Steve Green [a], David Horne [b], Ranvir Singh [b, c], Brent Clothier [a, c]

[a] The New Zealand Institute for Plant & Food Research Limited, Palmerston North, New Zealand
[b] Institute of Agriculture and Environment, Massey University, Palmerston North, New Zealand
[c] New Zealand Life Cycle Management Centre, Massey University, Palmerston North, New Zealand

A R T I C L E I N F O

Article history:
Received 5 October 2013
Received in revised form
18 May 2014
Accepted 5 June 2014
Available online xxx

Keywords:
Drainage
Nitrate leaching
Groundwater
Tension fluxmeter
Water quality

A B S T R A C T

Agriculture imposes demands on freshwater resources. Water footprinting has been proposed to quantify those impacts. To date, water footprints have been assessed only through modelling. We quantified the water footprint (WF) using measured soil water content and drainage under potatoes (*Solanum tuberosum*) grown in the Manawatu region of New Zealand. The net uses of groundwater and soil-water storage were considered to be the blue and green WFs, respectively. The drainage below the root zone was measured using tension fluxmeters over a cropping season and nitrate-nitrogen (NO_3-N) concentrations were analysed. The mean of the cumulative drainage was 263.8 mm (SE ± 84). Irrigation was not used, so the blue-WF was equal to the drainage. It was negative at −58.6 L/kg indicating that potato cultivation contributes to groundwater recharge. The green-WF was 15.8 L/kg. However, this green-water deficit would certainly be replenished, by winter rainfall. The grey-WF, the water needed to 'dilute' the leachate to the drinking water standard, was 133.1 L/kg of potato. The water quality impact based on the used-fraction of the nitrate assimilation capacity of groundwater was just 4.82×10^{-11} for a kg of potato. The NO_3-N leaching pattern reveals that some of the losses could be minimized through changed fertilizer practices. We estimated that 20 fluxmeters, rather than the six we used, would be needed to reduce the SE to 12.5% of the mean. Therefore, modelling will be the cost-effective means of quantifying the WFs. Nonetheless, model validation will always be necessary.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Hydrological sustainability is one of the most challenging issues the world is currently facing. Future food security is threatened by continued increase in the demand for water (Hanjra and Qureshi, 2010). Current observations and climate projections provide clear evidence that freshwater resources are vulnerable, and that they have the potential to be strongly affected by climate change. This will have wide-ranging and deep consequences for both humans and ecosystems (Bates et al., 2008). The challenge is to meet these additional food and freshwater demands in a way that does not affect natural capital stocks and the ecosystem services that flow from them. Higher crop productivity has traditionally involved intensive management and the use of high inputs such as irrigation, fertilizer and agrichemicals that can have potentially detrimental impacts on the environment. Optimizing water and nitrogen supply is the key to achieving higher and stable yields (Spiertz, 2012). Being the largest consumer of the world's water resources (UNEP, 2007), agriculture has widespread impacts on both freshwater quantity and quality. With increasing pressure on limited water resources, there is increasing interest in the metrics of the environmental impacts of water use by agricultural production systems.

The water footprint (WF) metric has been proposed as an indicator of the impacts of water use by agricultural production systems on freshwater resources (Ridoutt and Pfister, 2010; Deurer et al., 2011a; Herath et al., 2011). In water footprinting, three water colours are distinguished: blue, green and grey (Hoekstra et al., 2011). The 'blue water' refers to the surface and/or groundwater used by the production system. The 'green water' refers to the rain water used by plants that had previously been stored in the soil as soil moisture. The term 'grey water' is used to indicate water pollution due to leaching and runoff of agrichemicals from the production system.

* Corresponding author. Present address: Soils and Plant Nutrition Division, Coconut Research Institute, Lunuwila 61150, Sri Lanka. Tel.: +94 77 1762693.
E-mail addresses: indikaherath@hotmail.com, hmikherath@yahoo.com (I. Herath).

http://dx.doi.org/10.1016/j.jclepro.2014.06.026
0959-6526/© 2014 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Herath, I., et al., Quantifying and reducing the water footprint of rain-fed potato production, part I: measuring the net use of blue and green water, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.06.026

In agricultural production systems, water-related impacts are highly variable due to the variability in local climate and the heterogeneous nature of soil properties across the landscapes. Therefore, the accuracy of WF assessments is highly dependent on the ability of these methods to capture the variability of local impacts (Herath et al., 2013a). This local aspect becomes vital when exploring improvement options to reduce water use impacts, because the major impacts and reduction options have to be primarily focused on the cultivation and growing phase of agricultural products. Therefore, water use assessments using models at global scale have a limited use.

While international standards for water footprinting are in the process of being developed, there have been a number of extant protocols proposed to quantify the water footprint of agricultural products (Ridoutt and Pfister, 2010; Deurer et al., 2011a; Herath et al., 2011; Hoekstra et al., 2011). These different water-footprinting methods have their own advantages and disadvantages (Herath et al., 2013b). For example, the 'stress-weighted' WF is aimed at communicating water use impacts to the consumers or end users of the product (Ridoutt and Pfister, 2012). However, its ability to inform resource management is limited. The 'volumetric' WF is intended to be more useful in water resource management (Hoekstra et al., 2011). Among the various WF methods, the protocol for assessing the WF based on the water balance of the production system, which identifies the major inflows and outflows of the blue and green waters to/from the production system, has been shown to provide an unequivocal understanding of the hydrological impacts (Deurer et al., 2011a; Herath et al., 2011, 2013a,b).

Thus far, WFs of agricultural production have generally been assessed by estimating the hydrological components such as evaporation and transpiration of the system, through modelling (Chapagain et al., 2006; Chapagain and Orr, 2008; Dabrowski et al., 2009). This is because of the difficulty of measuring the green and blue water fluxes, and the challenge of quantifying the leaching and runoff of agrichemicals to surface and/or groundwater bodies. Most grey-water footprint calculations have, therefore, been simply based on the crude assumption that a fixed fraction of the applied fertilizer is lost through leaching (Chapagain et al., 2006; Dabrowski et al., 2009). This is a rough approximation that excludes critical factors, such as different soil types, various agricultural practices, variable local soil hydrological conditions and interactions among the different chemicals within the soil.

Measuring water and agrichemical dynamics under field conditions is expensive and time consuming. As a result, there has not been a focused assessment of water footprinting, especially for agricultural products, based on field measurement of water use and drainage. Therefore, the objective of this study was to attempt to quantify the WF of rain-fed potato production, through measuring the water use and leaching under field conditions. The viability of using measurements, rather than modelling, to quantify the WF is assessed. The advantages and difficulties of an empirical approach, rather than the use of modelling methodology are also outlined. We also use our measurements to identify options, to reduce the water footprint of potato cultivation.

2. Methodology

The most widely used method of water footprinting is the consumptive water-use method proposed by the Water Footprint Network (Hoekstra et al., 2011) that accounts for the amount of green and blue water consumed throughout the production system, plus the freshwater required to dilute the pollutants. However, this way of assessing the WF has been criticized for its inability to enable meaningful comparisons between the WF of products that are produced in locations of differing water-resource availability. Furthermore, it is considered that this method does not provide an indication of the environmental impact of the blue-water consumption (Ridoutt et al., 2009; Deurer et al., 2011a; Herath et al., 2013a). Therefore, alternative WF methods have been proposed by these authors. Among these methods, the hydrological water balance method has been identified as a useful method in understanding the impacts of water use, as well as setting limits to reduce these impacts (Deurer et al., 2011a; Herath et al., 2013a). Therefore, we used the principles of the hydrological water-balance method to assess water footprint in this study.

2.1. Measuring the impact of crop cultivation on the quantity of water resources: the blue and green water footprints

The impacts of potato growing in the Manawatu region of New Zealand, on local water resources, were assessed using the hydrological water balance method of WF (Deurer et al., 2011a; Herath et al., 2011). The impacts were assessed by considering the two main and intimately connected water resources: namely 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 (Deurer et al., 2011a; Herath et al., 2013b). The blue and green WFs indicate the impacts related to water quantity.

In this method, the green-water footprint is defined as the net change in the soil moisture storage (green water), and the blue-water footprint as the net change in the groundwater storage (blue water) (Deurer et al., 2011a; Herath et al., 2013b). We sought to quantify the net use of green and blue water by measuring the pattern of the daily change in the root zone soil moisture content and drainage under field conditions.

We studied this commercial-scale potato production system for the season 2011–2012. The soil type was Manawatu fine sandy loam (a Dystric Fluentic Eutrochrept) and is described in Clothier et al. (1978). In summary, the profile comprises a greyish brown fine sandy loam top soil, overlying olive-grey fine sand, which is then underlain to depth by gravelly coarse sand (Clothier et al., 1978). The soil is well-drained to moderately well-drained.

The annual average rainfall was 940 mm over the 40-year period of 1972–2012. Irrigation was not applied, since there was generally sufficient rainfall to meet the crop's water demand. The growing season began with the planting of the potatoes on 3 October 2011 and the crop was harvested on 15 April 2012. Measuring devices were installed at the start of the season immediately after planting, and the measurements were continued throughout the season. Tension fluxmeters were used to measure drainage under the root zone (Gee et al., 2002, 2009; Deurer et al., 2008). The fluxmeters comprise a convergence ring, a funnel, a hanging wick and a subterranean reservoir to collect the drainage (Fig. 1).

Six tension fluxmeters were installed and they were locally paired at three sites in the field, one under the ridge and the other close by in the furrow (Fig. 1). After installation of the fluxmeter assembly, the soil column above the convergence ring was repacked to the original sequence of the soil at relevant depths. The soil above the fluxmeters was carefully repacked in layers to the same bulk density. It is assumed that the soil's hydraulic properties became similar to that of the soil of the rest of the field. Drainage was collected after every significant rainfall event by connecting a vacuum pump to the outlet tube (Fig. 2). The volume of leachate was measured. Irrigation was not required for this potato production system. Therefore, there was no groundwater extraction by the production system. Drainage was considered to be equal to the net recharge of blue water resource and therefore, the blue-WF was negative (Eq. (1)). Surface runoff was considered negligible, since the landscape was flat to undulating and the soil is permeable

Download English Version:

https://daneshyari.com/en/article/8105773

Download Persian Version:

https://daneshyari.com/article/8105773

Daneshyari.com