Agricultural Systems 125 (2014) 33–41

Contents lists available at ScienceDirect

Agricultural Systems

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

Short Communication

WaterFootprint on AgroClimate: A dynamic, web-based tool for comparing agricultural systems

Daniel R. Dourte *, Clyde W. Fraisse, Oxana Uryasev

University of Florida, Agricultural and Biological Engineering, 1741 Museum Road, PO Box 110570, Gainesville, FL 32611, United States

ARTICLE INFO

Article history:
Received 4 April 2013
Received in revised form 6 September 2013
Accepted 24 November 2013
Available online 28 December 2013

Keywords:
Water footprint
Sustainability
Management
Efficiency
Water stress

ABSTRACT

We introduce a dynamic web-resource for estimating seasonal water footprints of agricultural production in the U.S. This tool provides a system-specific water footprint accounting that responds to changes in location, time, soil, and management. Modifications to an existing crop growth model were made in order to separate consumptive use of green and blue water; that is water from rainfall and water from a groundwater or surface water resource, respectively. This separation is an important distinction of water footprinting that allows for more direct assessments of impacts on water resources. The tool also provides a local water stress index, based on regional water use and available supplies, and it displays time series and cumulative rainfall during the period of crop production.

1. Introduction

A water footprint is a comprehensive measure of freshwater consumption that connects water use to a certain place, management system, time, and type of water resource. It is distinct from the common measure of water use, water withdrawals, because a water footprint only accounts for consumptive water use, which is water that becomes unavailable for reuse locally in the short term due to evaporation, incorporation into products, or a substantial quality decline. It has been used to evaluate the impacts of specific consumption and production practices on freshwater quality and sustainability. A water footprint can be calculated for a kilogram of wheat (Mekonnen and Hoekstra, 2010a), a jar of pasta sauce (Ridoutt and Pfister, 2010), a pizza (Aldaya and Hoekstra, 2010), a kilogram of milk (Zonderland-Thomassen and Ledgard, 2012), a barrel of oil (Dominguez-Faus et al., 2009), a pair of jeans (Chapagain et al., 2006), or for any kind of product, land area, consumer, business, or nation by following accounting practices that have been largely standardized by the Water Footprint Network (Hoekstra et al., 2011).

The calculation of a water footprint of a product can include the total amount of freshwater consumed along the supply chain of a product. An aspect of water footprinting that makes it especially valuable for sustainability and impact assessments is the separation of freshwater consumption into: (1) green water use, which is consumption from rainfall; (2) blue water use, which is consumption from groundwater or surface water; and (3) grey water use, which can be described as the dilution water required to reduce contaminant concentrations to acceptable values. It should be noted that the common definition of grey water as wastewater that might be reused is redefined in the water footprint literature as a theoretical volume of water required to reduce contaminant loads to a specified level. This distinction among green, blue, and grey water footprints recognizes that the consumptive use of rainfall, groundwater or surface water, and the water quality impacts all have different economic costs and ecological impacts.

Agriculture is responsible for 92% of the 9087 Gm^3 annual water footprint of humanity (Hoekstra and Mekonnen, 2012), and it is estimated (Mekonnen and Hoekstra, 2010) that 78% of the global agricultural water footprint is green (from rainfall), 12% is blue (irrigation from groundwater or surface water), and 10% is grey (freshwater contamination). Green, blue, and grey water footprints have been calculated for 126 crops and more than 200 crop-derived products at a global scale; crop-specific water footprints have been reported at national and state-level scales using weather data for 1996–2005 (Mekonnen and Hoekstra, 2010b). This extensive dataset provides excellent baseline estimates of agricultural water footprints. However, management and climate are not stable with time, and tools to estimate the water footprints of crop production for particular management systems and times can be valuable for stakeholders interested in water resource sustainability.

* Corresponding author. Tel.: +1 352 392 1864x220.
E-mail address: ddourte@ufl.edu (D.R. Dourte).

0308-521X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.agsy.2013.11.006

The WaterFootprint tool on AgroClimate (http://agroclimate.org/tools/Water-Footprint/), introduced here, is a user-friendly web-resource capable of simulating the system-specific green and blue water footprints for crop production in the United States. The dynamic nature of the tool allows for the comparisons of water footprints for varying management practices in agriculture for different seasons and regions in the U.S. The estimates from the tool can be used in the context of evaluating freshwater availability, water stress impacts, the effective use of rainfall, and the significance of irrigation. Presently, there is much discussion and research concerning adaptation of agricultural systems to a changing climate, but there are few metrics that can compare the resilience of different systems. A water footprint can serve as both a measure of resource-use efficiency and also as a tool for evaluating sustainability of freshwater systems. The objectives of this paper are to (1) introduce the AgroClimate WaterFootprint tool, (2) evaluate performance of the tool, and (3) demonstrate potential applications of the tool to show water footprint impacts from climate variability, management, and production region.

2. Methods

2.1. Web user interface

WaterFootprint on AgroClimate.org was designed to quickly and easily calculate the green and blue water footprints of an agricultural system for historical and recent seasons for a variety of production systems. Grey water is not accounted for as this requires much more detailed management data, and does not represent actual freshwater consumption, as it is more of an index for water quality impacts. The tool is hosted and maintained by AgroClimate.org (Fraisse et al., 2006; Fraisse, 2012), a web-based climate information and decision-support system that includes seasonal climate outlooks, expected impacts of management options for different crops and climate scenarios, and a wide variety of interactive tools that can help producers monitor current conditions and plan for the season ahead.

User inputs in WaterFootprint were streamlined in an effort to balance management system detail with the time required to run the tool. Presently, input data include (1) location, (2) crop, (3) planting and harvest dates, (4) yield as input or simulated, (5) soil texture, root zone depth, organic matter, (6) tillage, (7) irrigation management, and (8) fertilizer application. Location can be selected by clicking on a map or by inputting the zip code nearest to the production system. Crop choice is made by drop-down menu from five groups: Cereals, Pasture and forage, Fiber, Legumes, Fruits and vegetables, Sugar and stimulants. Currently, selection can be made from among 71 annual crops, but the addition of selected perennial species is under development. Dates of planting and harvest are input or selected from a calendar. Yield can be simulated by the tool or input; it is recommended that yield be input as this reduces uncertainty in the water footprint calculation, and it is expected that the yield for a system could be known if the other management data are known. Soil is described based on the HC27 generic/prototypical soil profiles that have been used for global crop modeling applications (Nelson et al., 2009). These simplified soil descriptions give three choices for texture (sandy, silty, clayey), three choices of root zone depth (60, 120, and 180 cm), and three choices of organic matter content (1.4%, 1.0%, and 0.4% in the top layer of soil). Tillage options are organized by groups: conservation, subsoil, conventional, weed-control. Tillage implement and direction (straight-row or contour) are used in the tool to adjust runoff Curve Number (SCS-CN; USDA, 1954). Three options are available to describe irrigation management: rainfed, auto-irrigation, and manual irrigation. For the auto-irrigation option, the model initiates an irrigation operation, filling the soil profile to field capacity, when the water stress exceeds a user-specified threshold. For manual irrigation, a seasonal total irrigation depth and average frequency of irrigation are specified by the user. Fertilizer forms are available for the possibility of adding functionality in the tool to account for water quality impacts; currently fertilizer application is automated based on plant nitrogen stress and a specified nitrogen stress factor threshold.

2.2. Water balance and crop growth simulation

Simulations of crop growth and water balances in the WaterFootprint tool make use of the EPIC crop growth model (Environmental Policy Integrated Climate; Williams et al., 1989) within the framework of the SWAT hydrology model (Soil and Water Assessment Tool; Arnold et al., 1998). EPIC uses a single, generic growth model to simulate all crops. Each crop is described in the model using approximately 30 plant-specific parameters. An implementation of EPIC was used for the AgroClimate WaterFootprint tool because it has been shown to be useful for broad, spatial assessments of water footprinting (Liu et al., 2007). SWAT is a landscape-scale hydrology model having physically-based process descriptions; it was used in the WaterFootprint tool because it contains an updated, streamlined implementation of EPIC for plant growth and it has physically-based, well-established routines for water balance modeling (Arnold et al., 1998; Gassman et al., 2007; Krysanvoa and Arnold, 2008) that provide some flexibility beyond what was available by using EPIC outside of the SWAT structure.

Calculating blue and green water footprints requires that total ET be separated into ET of rainfall (ET_{green}) and ET of irrigation from surface or groundwater (ET_{blue}). The WaterFootprint tool follows the guidelines of Hoekstra et al. (2011) to make this separation. ET_{green} is calculated as the minimum of effective rainfall (P_{eff}) and ET_{total}; $P_{eff} = P - DP - RO$, where P is rainfall, DP is deep percolation, and RO is surface runoff. In irrigated systems, ET_{blue} is the difference between ET_{total} and ET_{green}: $ET_{blue} = ET_{total} - ET_{green}$. These ET depths are converted to volumes (liters or gallons) and divided by yields (kg/ha or lb/ac) to calculate the blue and green water footprints.

The WaterFootprint tool uses the water stress index (WSI; Pfister et al., 2009) to provide information on the local, relative scarcity of freshwater resources. WSI at the location of the production system being simulated is retrieved from a WSI database for the U.S. WSI is a logistic function of WTA, the ratio of total annual freshwater withdrawals to annual hydrological availability. WTA is calculated from the WaterGAP2 global model that describes water use and annual availability, based on 1961–1990 climate period) for over 10,000 watersheds (Alcamo et al., 2003). WSI ranges from 0.01 (low water stress) to 1 (high water stress), and a value of 0.5 represents a threshold of severe water stress (Vorosmarty et al., 2000). Blue water equivalents or stress-weighted water footprints (Ridoutt and Pfister, 2010) can be calculated from WaterFootprint tool outputs by multiplying WSI and blue water footprint. The stress-weighted water footprint allows for regional water footprint comparisons that directly accounts for water scarcity.

2.3. Weather data

Daily weather data are required for the simulations of crop growth and hydrology. The most computationally expensive service of the WaterFootprint tool is the retrieval and formatting of daily weather data from a network of 5953 active U.S. weather stations that are part of the Global Historical Climatology Network – Daily (GHCN-Daily; Menne et al., 2012). The WaterFootprint tool selects the closest station with adequate data (complete records of