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Modeling the water demand on farms

K. Drastig[1], A. Prochnow[1,3], S. Kraatz[1], J. Libra[1], M. Krauß[1], K. Döring[1], D. Müller[1], and U. Hunstock[2]

[1]Leibniz-Institute for Agricultural Engineering Potsdam-Bornim, Germany
[2]runlevel3 GmbH, Kastanienallee 94, 10435, Berlin, Germany
[3]Humboldt-University of Berlin, Faculty of Agriculture and Horticulture, Chair Utilization Strategies for Bioresources, Hinter der Reinhardtstr. 8–18, 10115 Berlin, Germany

Correspondence to: K. Drastig (kdrastig@atb-potsdam.de)

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Abstract. The decreasing availability of water caused by depletion and climate change combined with a growing world population requires the productive use of water now and in the future. The young researcher group "AgroHyd" at the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB) is currently modeling the water demand for agricultural processes at the farm scale and developing indicators to link the hydrological and agricultural perspectives. The aim of the group is to increase productivity in agriculture by raising water productivity in plant production and livestock farming. The effects of various agronomic measures, individual and in combination, on water productivity are assessed using several indicators. Scenarios of agricultural measures, climate and diets are used to test to what extent the water demand for food production will increase due to growing global change in different regions of the world.

1 Introduction

The agricultural sector is facing enormous challenges with global change. In addition to the growing world population (from 6.6 billion people in 2010 to 9.2 billion people in 2050) and the increasing per capita demand for food energy (from 2850 kcal day^{-1} in 2010 to 3130 kcal day^{-1} in 2050), the rising share of food products of animal origin will entail a strong global increase in the demand for food-production resources (UNDP, 2006). Owing to the projected impacts of climate change, the spotlight is on water resources as the basis for agricultural production. Even without climate change, the water availability levels are expected to decline by 50 % to 6300 m^3 per capita by 2050, due to population growth alone (Ringler et al., 2010). Under conditions of climate change, agricultural land will be directly affected by increasing droughts, singular events like late frosts and torrential rains, and changes in the vegetation period.

In many regions of the world the over-use of water resources has led to a shortage of water, partly associated with deterioration in water quality and soil salinization, thus limiting the further expansion of irrigation in agriculture. In addition, increasing competition between the industrial sector, the private sector and the agricultural sector for water use is aggravating the limited availability of water. For about 15 yr now, although the area of irrigated land continues to grow, the growth rate has been decreasing (Rosegrant et al., 2002; Barker et al., 2000), while growth rates for water use in private and industrial applications are increasing. Water use in livestock farming is still low compared with water use for agricultural irrigation. However, with the growth of livestock farming in developing countries, related global water consumption is expected to increase by over 50 % by the year 2025 (Rosegrant et al., 2002).

Improving the productive use of water in both rainfed and irrigated agriculture for food production and for producing renewable raw materials is therefore of great importance.

Water productivity can be used as an indicator in the context of yield improvement ("more crop per drop"), as it shows the relation between water use and production of dry matter of crop plants on field scale. The water productivity on farm scale not only captures the yield improvement in one specific field, but can also be applied to the water value chain as an integrative indicator in order to measure enhanced use of water flows.

2 Background and previous research

Large amounts of water are used in agriculture. At the same time, water is often the limiting factor in many plant production systems due to its insufficient availability. In numerous international projects and publications, the problem of increasing over-utilization of the water resources is discussed and solutions are sought (e.g. de Fraiture and Wichelns, 2010). Systematic approaches to calculating the water demand in food production are the Water Footprint method (Allan, 1993; Chapagain and Hoekstra, 2004), the Life Cycle Assessment (Pfister et al., 2009; Milà i Canals et al., 2009), and the concept of Livestock Water Productivity (Descheemaker et al., 2010). The amount of water used to produce beef varies between 18 L kg^{-1} reported by Peters et al. (2010) and 15 500 L kg^{-1} (Hoekstra and Chapagain, 2006). This wide range is due to differences in the methods used for calculation, the assumptions made for the environmental conditions of production and the production procedures chosen. The method most frequently used so far is the Water Footprint method (Hoekstra et al., 2011), which divides the water demand of an agricultural product into three components – blue water (ground water and surface water), green water (precipitation and soil water), and grey water (waste water). For the determination of the water demand on farm scale, it is necessary to perform a methodological adjustment with the Inventory Analysis of the Life Cycle Assessment (LCA) described in ISO (2006a, b). First approaches for this purpose exist (Milà i Canals et al., 2006; Berger and Finkbeiner, 2010) but they need further systematic development to establish a standardized method that allows comparisons.

3 Research objectives

The objective of the project is to increase productivity in agriculture by raising water productivity on farm scale addressing the following questions:

- How can the water demand for food production on farms be calculated by way of the standard of the Inventory Analysis of LCA?
- Which indicators can be used to systematically assess the effect of measures to raise water productivity at the farm scale?
- What are the quantitative effects of the different agronomic measures to raise water productivity within plant production?
- What are the quantitative effects of the different agronomic measures to raise water productivity within livestock farming?
- How high is the water demand of entire chains of production from cradle to gate on farms?
- To what extent will water demand for food production increase due to growing global population, climbing incomes, rising urbanization and the associated increase in shares of food production of animal origin and other water-intensive food products?
- What agricultural measures to increase water productivity are the most suitable for farmers in different regions?

To calculate water flows for food production, an innovative method based on established standards from an agrohydrological perspective with a focus on the farm scale is to be developed. The concept of Livestock Water Productivity (Descheemaker et al., 2010) is used, in order to analyze and quantify measures serving to raise water productivity in plant production and livestock farming on farm scale. The water productivity is used as an indicator for yield improvement ("more crop per drop"), as it shows the relation between water use (m^3) and the production of on-farm produced products (e.g. expressed as kg crop, kg feed, kg milk or kg meat). This approach is combined with a methodology for the estimation of water flows at the farm scale recently developed at the ATB Prochnow et al. (2012). The system is the individual farm. The spatial boundaries of the system are set from an institutional perspective in the sense that any physical thing that belongs to the farm also belongs to the system. The water flows into and out of the system are determined as shown in Fig. 1.

All water flows will be considered that enter or leave the farm system regardless of whether they are used or not for agricultural production. The direct water flows, e.g. precipitation, tap water, irrigation water, transpiration, interception losses from plant leaves and mulch, deep percolation and evaporation from soil will be taken into account. However, animal perspiration and respiration will not be considered, nor will be any evaporation due to leakage in the animal cleaning and drinking systems. Indirect water flows will be considered in the calculations. These are water flows associated with materials used on the farm from previous stages in their life cycle, i.e. water used for the construction of farm buildings and machines, as well as for imported feed.

For the calculation of the water productivity parts of the water inflows into the farm system are assigned to the generation of farm output. The farm operating data is generated through interviews with farmers, while the other data stems from local, federal, and international services. From these values for the water flows and the farm output generated, water related indicators are calculated for the farm system.

The aim of the group is to increase productivity in agriculture by assessing farm water use. This entails first quantifying current water productivity using e.g. the indicators Farm Water Productivity, Degree of Water Utilization and Specific Inflow of Technical Water following Prochnow et al. (2012). Then management options to improve the water productivity can be evaluated. The approach described above has been implemented in the modeling system of the AgroHyd-group

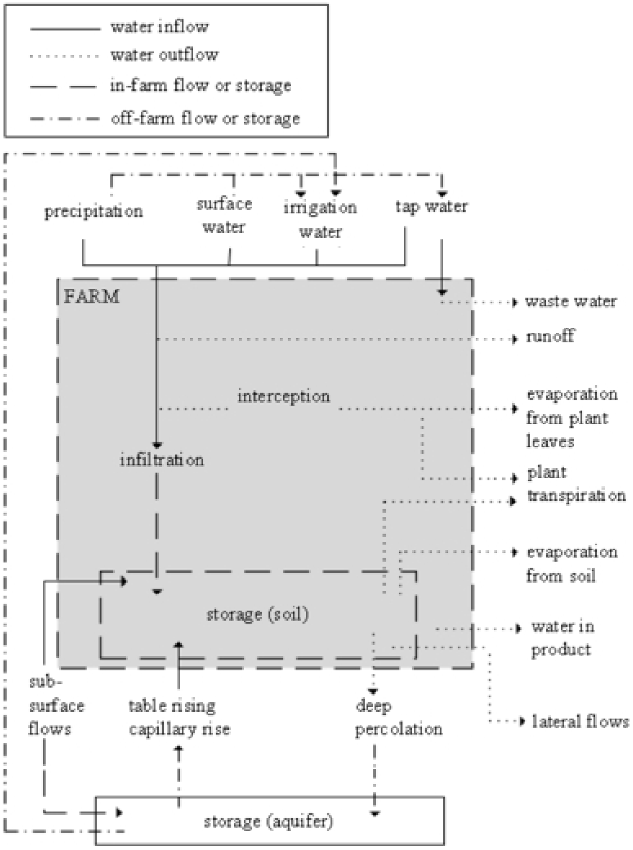

Fig. 1. System boundaries and water inflows and outflows for the calculation of the water demand at the farm level. Perspiration and respiration of animals will not be considered. Evaporation within livestock may appear due to leakage of the cleaning and drinking systems.

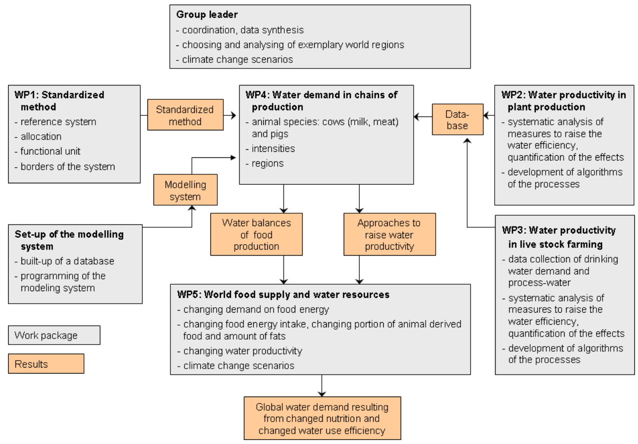

Fig. 2. Work arrangements and group structure.

ATB-Database that allows the modeling of the water fluxes and calculation of indicators within farms for food production at the farm scale. This enables the calculation of the water demand of typical modes of alimentation based on literature research.

Through the synergy of the hydrological and agronomical approaches, the project result provides an innovative possibility to adapt agricultural production to global changes.

4 Work packages and partners

4.1 Work packages

The project is divided into five work packages as illustrated in Fig. 2, which build on and complement one another.

Within the work package *standardized method (WP1)*, a standardized method to calculate the water flows for food production is developed. For selected farming systems (e.g. dairy farming, Kraatz, 2008) the effects of variations in the methodological approach, e.g. different allocation approaches and the functional units used, are studied. The impact on the balance results is evaluated in terms of a sensitivity analysis.

The influence of the different allocation approaches on the indicators will be investigated and the most suitable allocation approach will be chosen. The applicability of different functional units e.g. mass, or content expressed as food energy, nutrient or vitamin, will be investigated for different applied questions in detail.

The multifunctionality of agricultural production processes will be considered by using allocation of the water demand related to the specific products (e.g. milk and meat in dairy farming). Within the working group, the further processing of the products is neglected. The preceding process sequences, i.e. the water demand for producing farm inputs, buildings and machinery, will be included proportionately. After examining the different methodological approaches, a standard will be derived to describe the modeling in detail, and tables of reference values for single parameters will be developed.

In the work packages *water productivity in plant production (WP2) and water productivity in livestock farming (WP3)*, the effects of individual measures are quantified by using indicators following Prochnow et al. (2012), interactions are analysed, and especially effective, site-specific measures are derived (Drastig et al., 2011). For this purpose, literature data are interpreted; algorithms developed and own modeling and simulations implemented. The resulting modules and databases allow us to quantify water productivity in plant production under different site-specific conditions, and to quantify a broad spectrum of measures in plant production and livestock farming. The data obtained from these two work packages is assembled into a database, which in turn is further processed in work package 4.

In *WP2*, investigations concentrate on exemplary areas of domestic plant production (pea, sugar beet, sorghum, rice, potatoes, barley, wheat, oilseed rape, maize, rye, triticale, pasture (timothy and clover), alfalfa).

Table 1. Characteristics of the crop rotations that will be investigated.

Code	1st year	2nd year	3rd year	4th year
B-W-F	winter barley (*Hordeum vulgare* L.)	winter wheat (*Triticum aestivum* L.)	fallow	
R-W-B	oilseed rape (*Brassica napus)*	winter wheat (*Triticum aestivum* L.)	winter barley (*Hordeum vulgare* L.)	
M-Ry-T-M	maize (*Zea mays* L.)	rye (*Secale cereale* L.)	triticale (*Triticosecale Wittm. ex A. Camus.)*	maize (*Zea mays* L.)
M-Ry-T-Ry	maize (*Zea mays* L.)	rye (*Secale cereale* L.)	triticale *(Triticosecale Wittm. ex A. Camus.)*	rye (*Secale cereale* L.)
M-Ry-M	maize (*Zea mays* L.)	rye (*Secale cereale* L.)	maize (*Zea mays* L.)	
R-W-Ry-M	oilseed rape (*Brassica napus*)	winter wheat (*Triticum aestivum* L.)	rye (*Secale cereale* L.)	maize (*Zea mays* L.)
M-R-P	maize (*Zea mays* L.)	rye (*Secale cereale* L.)	pasture (*Trifolium pratense* L.)	fallow
A-M-M	alfalfa (*Medicago sativa* L.)	alfalfa (*Medicago Sativa* L.)	maize (*Zea mays* L.)	maize (*Zea mays* L.)
P-M-P	pasture (*Phleum pratense* L. and *Trifolium pratense* L.)	maize (*Zea mays* L.)	pasture (*Phleum pratense* L. and *Trifolium ratense* L.)	

Notes: B = winter barley; W = winter wheat; R = oilseed rape; SF = sunflower; M = maize; SG = sorghum; T = triticale; A = alfalfa; P = Pasture (timothy and clover).

The following measures are investigated with regard to a quantitative increase in water productivity:

– cropping and tillage systems and the resulting water retention capacity of soils as a function of the amount of organic soil matter are considered,

– crop rotations and intermediate crops are investigated,

– fertilizing in order to guarantee a sufficient nutrient supply and to support root formation is analyzed,

– regional characteristics as climate and soil are analyzed.

Examples for investigated crop rotations can be best seen in Table 1,

In work package 3 (*WP3)* the water demand in livestock farming (dairy farming and beef production) is calculated. The water flows of the farm system are recorded and modeled to determine the water productivity of livestock operations. The following measures are investigated with regard to a quantitative increase in water productivity:

– feeding strategies,

– breed,

– farming intensities, and

– regional characteristics.

The amount of water used in different milking systems will be compared and analyzed. The first calculations are made for conditions in North-East-Germany. Diet ingredients are grass silage, maize silage, hay, pasture, beet pulp silage, soybean meal, rapeseed meal, grain and concentrate. In a later phase of the project other regions and additional livestock farming systems (e.g. pork production) are targeted.

Work packages 1, 2 and 3 are each being carried out by one PhD student.

Within the work package *water demand in chains of production (WP4)*, the modeling system used for calculating the water demand in different farms for entire chains of food production is developed and applied. The technician is currently programming the modeling system ATB-Database. Various systems for producing plant-derived food, such as cereals, maize, potatoes and cooking oils, are investigated. Livestock farming systems (dairy farming, beef and pork production) are analyzed, including feed production and replacement. The standardized method from WP 1 is applied for the calculation of the water demand. The modules and databases from WP 2 and 3 are integrated into the model system and enable a flexible variation of numerous parameters for different systems of plant production and livestock farming. This supports the determination of water productivity of varying site conditions, intensities of land-use and methods of livestock farming. Extensive and intensive production processes are covered with this study. The impacts of individual measures and combinations of measures on the overall system, as well as impacts of variations in the system (e.g. higher milk yield or longer service life of dairy cows) in various regions are investigated. Globally relevant regions are chosen for closer investigation. As a result, the water demand and the effect on the indicators for different food production processes can be identified cradle to gate and measures to increase water productivity of the total system can be determined.

In the work package *world food supply and water resources (WP5)*, the projections for agricultural water use at the farm-scale will be linked to the regional and global levels in order to develop policy options for decision makers. Through such linkages, changes in potential water demand as a function of farm management practices can be calculated. Then projections for water productivity and water use can be developed for different regional and world food supply scenarios, taking climate scenarios into account as well.

The steps to develop the scenarios entail choosing typical diets for selected regions, climate scenarios, and then estimating the associated water demand. The daily food energy intake, the portion of food of animal origin and the amount of fats is varied in the diet scenarios. The demand for food resulting from these typical diets and the associated water demand for producing this food is calculated for varying water productivity (data from WP 4) and climates. Initial scenarios are being developed for the Berlin/Brandenburg region of Germany. Information on the dietary needs of the population in this region, the required area for cropland and pasture to produce the necessary crops and meat is used to calculate the specific water required for each diet ($m^3\,J^{-1}\,yr^{-1}$). For the climate scenarios in Europe, the non-hydrostatic Climate model of the Local Model of the German Weather Service (DWD) CLM 2.4.11 will be used. The simulation period from 1960 to 2100 with the IPCC emission scenarios A1B, B1 (from 2001) is available.

4.2 Partners

The scenarios are selected in close coordination with the cooperation partner C. Ringler at the International Food Policy Research Institute, Washington DC, USA (IFPRI). The postdoctoral researcher will work with the IFPRI global water simulation model and a global world food supply model, gaining expertise as a special qualification. Conclusions will be drawn as to how the water demand will develop with different world food supply scenarios, taking climate scenarios into account too, to determine what measures for raising water productivity in the overall system are the most efficient.

5 Outlook

The work on the subject is carried out on an interdisciplinary basis and under consideration of strategic aspects. The issue of the globally relevant shortage of resources is dealt with – an innovative approach in securing food supplies is being developed. The supply of water resources is a crucial factor in agricultural food production. The novel interdisciplinary combination of expertise in experimental agricultural science and measures to improve water productivity in agricultural operation systems opens up a new and forward-looking field of research at the interface between agricultural science, agricultural engineering and hydrology. The intention of the AgroHyd-group is to contribute significantly to answering the following key question: how can an increase in agricultural productivity be achieved by an increase in water productivity?

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