Environmental Research Letters

OPEN ACCESS

PUBLISHED
30 August 2016

PERSPECTIVE

Pathways to sustainable intensification through crop water management

Graham K MacDonald[1], **Paolo D'Odorico**[2] **and David A Seekell**[3]

[1] Department of Geography, McGill University, Montreal, Canada
[2] Department Environmental Sciences, University of Virginia, Charlottesville, VA, USA
[3] Department of Ecology and Environmental Science, Umeå University, Umeå, Sweden

E-mail: graham.macdonald@mcgill.ca

Keywords: irrigation, food security, virtual water, food trade, water managment

Abstract

How much could farm water management interventions increase global crop production? This is the central question posed in a global modelling study by Jägermeyr *et al* (2016 *Environ. Res. Lett.* **11** 025002). They define the biophysical realm of possibility for future gains in crop production related to agricultural water practices—enhancing water availability to crops and expanding irrigation by reducing non-productive water consumption. The findings of Jägermeyr *et al* offer crucial insight on the potential for crop water management to sustainably intensify agriculture, but they also provide a benchmark to consider the broader role of sustainable intensification targets in the global food system. Here, we reflect on how the global crop water management simulations of Jägermeyr *et al* could interact with: (1) farm size at more local scales, (2) downstream water users at the river basin scale, as well as (3) food trade and (4) demand-side food system strategies at the global scale. Incorporating such cross-scale linkages in future research could highlight the diverse pathways needed to harness the potential of farm-level crop water management for a more productive and sustainable global food system.

Much of the promise for the sustainable intensification of agriculture needs to come from closing crop yield gaps across underperforming areas [1, 2]. Jägermeyr *et al* [3] assess the global potential of farm water management to close yield gaps, revealing that calorie production could be increased by 18%–60% on existing agricultural lands. Their analysis defines the biophysical realm of possibility for agricultural production related to water management—offering a new 'benchmark' to assess the potential for sustainable intensification. A growing body of research on the biophysical potential for sustainable intensification raises new questions about how such global supply-side interventions (including, but not limited to, farm water management) might interact with other dimensions of the food system. Here, we consider a series of potential interactions in the context of the findings from Jägermeyr *et al* for farm water management.

Water management is central to enhancing yields in many regions, with the aim being to get more 'crop per drop' [4, 5]. To this end, Jägermeyr *et al* [3] consider a mix of four soil-water water management interventions to minimize non-productive water consumption in agriculture (defined as 'integrated crop water management'): reducing soil evaporation for enhanced crop water productivity, capturing surface runoff for supplemental irrigation, increasing soil infiltration capacity for rainfed crops, and improving irrigation system efficiency in order to expand irrigated areas by using the saved water. Reducing soil evaporation has been widely discussed (see Falkenmark and Rockström [6, 7]), but assessment of its role in closing yield gaps globally is novel and informative. Nonetheless, reducing non-productive water consumption in irrigated systems seems to offer the greatest potential crop production increases by providing the water needed to expand irrigation [3]. This is logical given that irrigated yields typically exceed those of rainfed systems—for example, cereal crops in irrigated systems yield ~1.7× more globally than non-irrigated cereals [8].

Jägermeyr *et al* make important strides in pinpointing the potential to close yield gaps relative to the biological and hydrologic processes of agriculture, for which they outline myriad potential co-benefits,

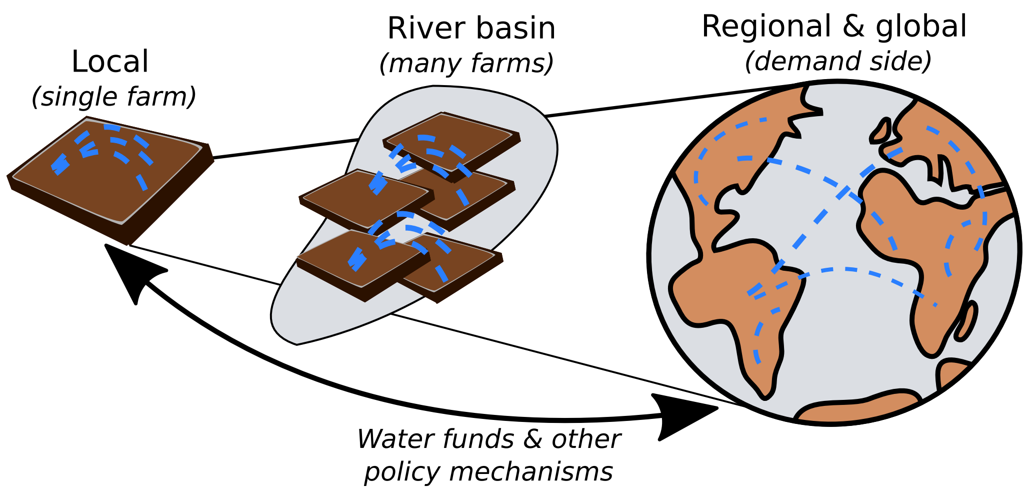

Figure 1. Cross-scale considerations relevant to the widespread application of ambitious farm water management interventions for sustainable intensification. At the local scale, impacts on farming systems are important considerations (e.g., how farm size, capital costs, and smallholder farming system characteristics could be affected); at the basin scale, competing demands for land and water along the river network are important considerations (e.g., potentially large land requirements for water storage ponds and impacts of upstream water diversions on downstream water users, including inland fisheries); at larger scales, demand-side factors could have greater cumulative impacts on food availability while still contributing to reductions in agricultural water consumption. Global trade could be both a way to help pay for farm-level water management interventions and to save water by taking advantage of efficiency gains in the virtual water trade network. Global map outline by Dieter Tracey, Integration and Application Network, University of Maryland Center for Environmental Science (http://ian.umces.edu/imagelibrary/).

including increased capacity to buffer against the impacts of climate change. Such advancements in global agriculture research provide a solid foundation to consider how biophysical dimensions of sustainable intensification might link to broader social-environmental factors related to all stages of food production, distribution, and consumption. Using the findings of Jägermeyr *et al* [3] and their 'ambitious yet achievable' scenario of global crop water management interventions, we briefly outline four questions and avenues for future research related to the role of sustainable intensification targets in the global food system more generally (figure 1). These questions are intended to complement the findings of past research by identifying potential barriers to and facilitators of crop water management interventions at distinct scales.

How might ambitious farm water management interventions to achieve global sustainable intensification targets affect local smallholder farming systems?

Jägermeyr *et al* evaluate their global simulations using national or regional studies on water harvesting, mulching, and soil moisture conservation, but a closer look at local diversity in farming systems is a logical next step. Notably, their simulations involve large tracts of key crops (e.g., pulses, soybean, cotton, coffee, and sunflower) being converted to more efficient drip irrigation [9], which would carry large upfront capital costs. Simple drip irrigation and water harvesting methods may be accessible and greatly beneficial to smallholder farmers [10], but the coordination involved in the most ambitious scenario simulated by Jägermeyr *et al* may only be achievable with a transition away from small scale family farming toward larger, more commercialized agriculture in key areas where some of the greatest potential productivity gains exist. For example, national agricultural censuses commonly define smallholder and medium-sized farms as being <10 hectares in size, and such farms comprise the majority of agricultural land areas in countries where Jägermeyr *et al* find among the largest potential to increase calorie production (e.g., Ethiopia, Pakistan, India, and China) [11]. Other soil water conservation practices (intercropping, mulching or no-tillage agriculture) require more modest investments and are likely more accessible to all farmers.

How might widespread integrated crop water management interventions compete with other uses of land and water at the river basin scale?

Widespread water harvesting for agriculture would likely require a large amount of land—as much as 1 hectare of ponds for every 10 hectares of farmland [12]—representing an important constraint when moving from biophysical models to application of water management interventions. Additionally, while capturing surface runoff for irrigation may be a good idea when viewed solely in terms of global crop production potentials, the appropriate environmental flow requirement thresholds could vary widely across basins (as shown by Gerten *et al* [13] using different methods to assess aquatic ecosystem needs). Maintenance of environmental flows could have further value downstream given the vital role of inland fisheries in regional food security, such as that of the Mekong River in Southeast Asia [14]. Moves to optimize water for crop production therefore may not serve all food security goals in the same way across all river basins globally.

Could global trade be a mechanism to help scale farm-level water management interventions?

Food trade is increasingly important to both food security and water resource management [15], with considerable populations fundamentally dependent on food imports due to local renewable water constraints [16, 17]. Global irrigation water consumption associated with agricultural exports, including animal and industrial products, is ∼301 km^3 yr^{-1} [18]—roughly one quarter of the irrigation water consumption (1268 km^3 yr^{-1}) simulated by Jägermeyr *et al* for their 12 crop functional types. Reducing non-productive water consumption for a few highly traded and water-intensive crops could dramatically reshape the global landscape of virtual water trade. More than half (55%) of virtual irrigation water consumption is linked to seed cotton alone [18]—a 'thirsty' crop in comparison to cereals and other food staples that, despite its economic value, has a negligible role in global food production. Additional research is needed to understand how trade patterns and total water consumption might change under widespread crop water management targets [19], particularly in sub-Saharan Africa, where yield gaps are pronounced and market access is a major barrier to sustainable intensification [20]. At the global scale, improved crop water management in export-producing countries could reinforce the water savings potential of international food trade resulting from relative gains in water-use efficiency among trade partners [21].

How does sustainable intensification compare to more demand-side interventions?

Food security is not guaranteed by increased food production alone—it encompasses multiple complex factors that determine accessibility to food at different scales, including purchasing power, socio-political context, and access to distribution channels [22]. Growing demand for more resource-intensive foods exerts increasing pressures on land and water [23], and contributes disproportionately to the 60%–100% projections of future crop calorie demand targeted by Jägermeyr *et al* [3]. Shifting diets away from animal protein in favour of local crop-derived proteins has the potential to reduce irrigation water consumption by as much as 14% [24] while substantially cutting supply chain food losses and waste could reduce it by 12% [25]. Diets, waste, and governance are therefore critical determinants of the extent to which crop production actually needs to increase in order to ensure global food security [1, 22].

A critical challenge for agriculture this century will be to do more with less. Global biophysical modelling studies, including that of Jägermeyr *et al*, offer vital benchmarks to help assess supply-side strategies toward a more sustainable and productive food system. A crucial next step to harness the immense potential of crop water management and other more supply-side strategies in achieving this goal is to assess location-specific pathways to sustainable intensification based on farming system characteristics [20]. Synthesis of local case studies could assess the appropriateness of specific farm management interventions and account for the cultural and economic diversity of smallholder farming systems [26]—possibly favouring less effective but more feasible soil water conservation techniques in some areas. Water funds could be a critical policy mechanism to help incentivize farm water management interventions within individual basins [27], and such markets could help to moderate the potential tradeoffs with downstream water users described above. The role of agricultural trade as both a facilitator and outcome of sustainable intensification targets also warrants further assessment. Since consumers in virtual water importing nations benefit from water resources in exporting countries, novel international water funds or payment for ecosystem services schemes could be a further policy consideration to integrate supply- and demand-side strategies in agricultural water management (figure 1). Improved crop water management will be essential to help address global food production and freshwater availability this century. Further untangling the diversity of local pathways needed to scale integrated crop water management is a key next step for global research.

References

[1] Godfray H C J and Garnett T 2014 Food security and sustainable intensification *Phil. Trans. R. Soc.* B **369** 20120273

[2] Mueller N D, Gerber J S, Johnston M, Ray D K, Ramankutty N and Foley J A 2012 Closing yield gaps through nutrient and water management *Nature* **490** 254–7

[3] Jägermeyr J, Gerten D, Schaphoff S, Heinke J, Lucht W and Rockström J 2016 Integrated crop water management might sustainably halve the global food gap *Environ. Res. Lett.* **11** 025002

[4] Postel S L 1998 Water for food production: Will there be enough in 2025? *BioScience* **48** 629–37

[5] Brauman K A, Siebert S and Foley J A 2013 Improvements in crop water productivity increase water sustainability and food security—a global analysis *Environ. Res. Lett.* **8** 024030

[6] Falkenmark M and Rockström J 2004 *Balancing Water for Humans and Nature: the New Approach in Ecohydrology* (London: Routledge)

[7] Falkenmark M and Rockström J 2006 The new blue and green water paradigm: breaking new ground for water resources planning and management *J. Water Res. Plan. Manag.* **132** 129–32

[8] Siebert S and Döll P 2010 Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation *J. Hydrol.* **384** 198–217

[9] Jägermeyr J, Gerten D, Heinke J, Schaphoff S, Kummu M and Lucht W 2015 Water savings potentials of irrigation systems:

global simulation of processes and linkages *Hydrol. Earth System Sci.* **19** 3073–91
[10] Postel S, Polak P, Gonzales F and Keller J 2001 Drip irrigation for small farmers: a new initiative to alleviate hunger and poverty *Water Int.* **26** 3–13
[11] Graeub B E, Chappell M J, Wittman H, Ledermann S, Kerr R B and Gemmill-Herren B 2016 The state of family farms in the world *World Develop.* **87** 1–15
[12] Baker J M, Griffis T J and Ochsner T E 2012 Coupling landscape water storage and supplemental irrigation to increase productivity and improve environmental stewardship in the US Midwest *Water Resour. Res.* **48** W05301
[13] Gerten D, Hoff H, Rockström J, Jägermeyr J, Kummu M and Pastor A V 2013 Towards a revised planetary boundary for consumptive freshwater use: role of environmental flow requirements *Curr. Opinion Environ. Sustain.* **5** 551–8
[14] Dugan P, Dey M M and Sugunan V V 2006 Fisheries and water productivity in tropical river basins: enhancing food security and livelihoods by managing water for fish *Agric. Water Manag.* **80** 262–75
[15] Porkka M, Kummu M, Siebert S and Varis O 2013 From food insufficiency towards trade dependency: a historical analysis of global food availability *PLoS One* **8** e82714
[16] Fader M, Gerten D, Krause M, Lucht W and Cramer W 2013 Spatial decoupling of agricultural production and consumption: quantifying dependences of countries on food imports due to domestic land and water constraints *Environ. Res. Lett.* **8** 014046
[17] Suweis S, Rinaldo A, Maritan A and D'Odorico P 2013 Water-controlled wealth of nations *Proc. Natl Acad. Sci.* **110** 4230–3
[18] Hoekstra A Y and Mekonnen M M 2012 The water footprint of humanity *Proc. Natl Acad. Sci.* **109** 3232–7
[19] Springer N P and Duchin F 2014 Feeding nine billion people sustainably: conserving land and water through shifting diets and changes in technologies *Environ. Sci. Technol.* **48** 4444–51
[20] Vanlauwe B, Coyne D, Gockowski J, Hauser S, Huising J, Masso C, Nziguheba G, Schut M and Van Asten P 2014 Sustainable intensification and the African smallholder farmer *Curr. Opinion Environ. Sustain.* **8** 15–22
[21] Konar M, Reimer J J, Hussein Z and Hanasaki N 2016 The water footprint of staple crop trade under climate and policy scenarios *Environ. Res. Lett.* **11** 035006
[22] Loos J, Abson D J, Chappell M J, Hanspach J, Mikulcak F, Tichit M and Fischer J 2014 Putting meaning back into 'sustainable intensification' *Front. Ecol. Environ.* **12** 356–61
[23] Davis K F and D'Odorico P 2015 Livestock intensification and the influence of dietary change: a calorie-based assessment of competition for crop production *Sci. Total Environ.* **538** 817–23
[24] Jalava M, Kummu M, Porkka M, Siebert S and Varis O 2014 Diet change—a solution to reduce water use? *Environ. Res. Lett.* **9** 074016
[25] Kummu M, De Moel H, Porkka M, Siebert S, Varis O and Ward P J 2012 Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use *Sci. Total Environ.* **438** 477–89
[26] Magliocca N R *et al* 2015 Synthesis in land change science: methodological patterns, challenges, and guidelines *Regional Environ. Change* **15** 211–26
[27] Goldman-Benner R L *et al* 2012 Water funds and payments for ecosystem services: practice learns from theory and theory can learn from practice *Oryx* **46** 55–63