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183. E.T.: An operational field water and salt flows model for agricultural LCA illustrated on a Moroccan Mandarin

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ABSTRACT

Objectives: Water inventory and agri-food LCA databases do not fully support the application of LCIA methods assessing the impacts of consumptive and degradative water use (so-called water availability as proposed by Boulay and colleagues), and are not appropriate for LCA-based ecodesign of cropping systems. For herbaceous crops, the FAO Aquacrop model constitutes a relevant and operational model for estimating field water and salt flows, but no dedicated model is available to-date for perennials. The objectives of this work were (i) to develop a simple and operational model for the estimation of field water and salt flows, aiming at discriminating practices for all types of cropping systems including perennials, (ii) to test and discuss its feasibility in a demanding case study. ***Methods:*** After a review of modelling approaches, we elaborated a tailored model, called the E.T. model, for the inventory of field water and salt flows for use in LCA of cropping systems. The model has a daily water and salts balance, accounting for specific soil, climate and agricultural practices. We explored the model relevance and robustness in a case study of a mandarin crop grown in Morocco, based on farm primary data. We compared the model outputs with the literature and water databases, and calculated water availability impacts. ***Results:*** The E.T. model is simple and operational on perennial crops, and estimates evaporation, transpiration, deep percolating water and runoff water, in terms of volume and salinity. Its outputs compared well with literature and measurements, and allowed the simulation of scenarios of agricultural practices. A comparison with crop water consumption estimates from databases highlighted a difference of up to 60%. E.T. model outputs are water elementary flows and salinity and can be used for assessing the impacts of consumptive and degradative water use in LCA. ***Conclusions:*** The E.T. model supports the calculation of water availability impact while discriminating agricultural practices. Its domain of validity and accuracy could be extended based on recommendations from the authors.

Keywords: water inventory, water impacts, crop, perennial, evapotranspiration

1. Introduction

In the context of flourishing eco-labelling programs and environment policy for food products, LCA applied to agricultural systems faces the challenges of being operational, accurate and exhaustive. Indeed, LCA has to include all major environmental impacts including water deprivation. This is particularly challenging for the water use impact assessment in LCA, which is relatively new, with many LCIA methods only recently developed. Among these methods, we can distinguish water scarcity indicators (that only recognise the contribution of water quantity to water deprivation, e.g. Pfister et al. 2009) from water availability indicators (where both water quantity and quality contribute to water deprivation, e.g. Boulay et al. 2011a&b).

Water inventory databases (e.g. WaterStat (WFN 2015)) and agri-food LCA databases (e.g. World Food LCA Database (Nemecek et al. 2015)) contain default water elementary flows for average crop and crop products. These databases support the application of LCIA methods to assess the impacts of water consumption (but not water degradation), for agricultural systems at the background level in the life cycle of food products. They provide only theoretical crop water consumptions that may differ a lot from the water actually withdrawn and consumed, and rely on data and approaches with important limitations, making them inappropriate for agricultural LCA studies where an adaptation of practices is sought (Payen 2015, Payen et al. submitted). Furthermore, in these databases, salt flows in relation to agricultural practices such as irrigation are not accounted for, even though salinisation represents one of the major threats for agricultural systems over the world.

For the LCA-based ecodesign of cropping systems, the inventory of water flows should be based on a model simulating evapotranspiration, deep percolation and runoff accounting for crop specificities, pedo-climatic conditions and agricultural management practices (Payen, 2015). In

particular, the model should account for possible water, saline and nutrient stresses; assess evaporation and transpiration separately and estimate runoff and drainage according to the systems specificities. Yield should not be a model output but primary datum (Payen, 2015).

A review of water and salt flows models (Payen et al. submitted), revealed that the recent FAO model Aquacrop (Steduto et al. 2012) is a relevant tool for estimating water and salt flows for the inventory of agricultural LCA, due to an optimal balance between accuracy, simplicity and robustness. However, while this model is operational for annual crops, no similar model exists to-date for perennial crops. Because the need for an operational tool for field water and salt flows in perennial cropping systems is urgent, even with a scarcity of available data, the objectives of this work were:

(i) to develop a simple and operational model for the estimation of field water and salt flows, aiming at discriminating practices for all types of cropping systems including perennials,

(ii) to test its feasibility in a demanding case study; assessing water availability impacts for a mandarin crop grown in Morocco.

2. Methods

2.1. Model description

We did not create a new model from scratch, but elaborated on a tailored model fulfilling our objectives based on old and robust formalisms completed with recent data on transpiration. Based on actual water supply (volume and salinity) and the soil, climate and practice specificities, the model estimates the water consumed through evapotranspiration, and the water released in the environment through deep percolation and runoff. Regarding the water quality, the model accounts for salinity through two aspects: i) its effect on the water balance, and ii) its effect on the environment through emissions. Indeed, salinity of soil water may reduce evapotranspiration (due to osmotic effects), thus affecting all other water flows. The model estimates the salinity of deep percolating water and soil water. Salinity is estimated through the electrical conductivity (in $dS.m^{-1}$) of the water, and assuming a conversion factor to $g.L^{-1}$ equal to 0.64 (USDA-NRCS 2015).

The model consists of daily water and salt balances (Figure 1). In a schematic way, soil is considered a uniform reservoir in which the soil water and salt content changes as a result of incoming and outgoing water and salt flows. The input data required (on a daily basis) are the depth (in mm) of irrigation water and rainfall, and the electrical conductivity (in $dS.m^{-1}$) of the irrigation water. Climate data (e.g. relative humidity, rainfall frequency) and crop physical characteristics data (e.g. crop mean height, fraction of ground covered by vegetation) are also required for the calculation of evaporation and transpiration. Evaporation and transpiration are calculated separately, which is particularly relevant for orchards or vineyards where evapotranspiration is more complex than a uniform herbaceous crop. The transpiration module is specific to the crop, which in our case study is citrus, through the key factor of leaf resistance. A lack of water or an excess of salts in the soil water can reduce crop water consumption. Thus, to estimate <u>actual</u> evapotranspiration ET_a, the model computes stress coefficients that reduce the potential evapotranspiration ET_c according to Allen et al. (1998). The model is called E.T. because the EvapoTranspiration module is crucial. Default data can be used if primary data are not available for crop physical characteristics (Allen et al. 1998), water salinity (UNEP 2009), soil characteristics (Batjes 2006, FAO/IIASA/ISRIC/ISS-CAS/JRC 2012) and climate data (Mitchell and Jones 2005, New et al. 2002).

The E.T. output variables are water flow volumes and salinity. Additional calculations are required to convert the hydrological water flows to water inventory flows usable in LCA. The total actual evapotranspiration (ET_a) is further divided into its green ($ET_{a\ green}$, effective rainfall) and blue ($ET_{a\ blue}$, irrigation water) components. The effective rainfall is the part of the rainfall which is actually available to the crop for evapotranspiration; rainfall minus losses through runoff and deep percolation.

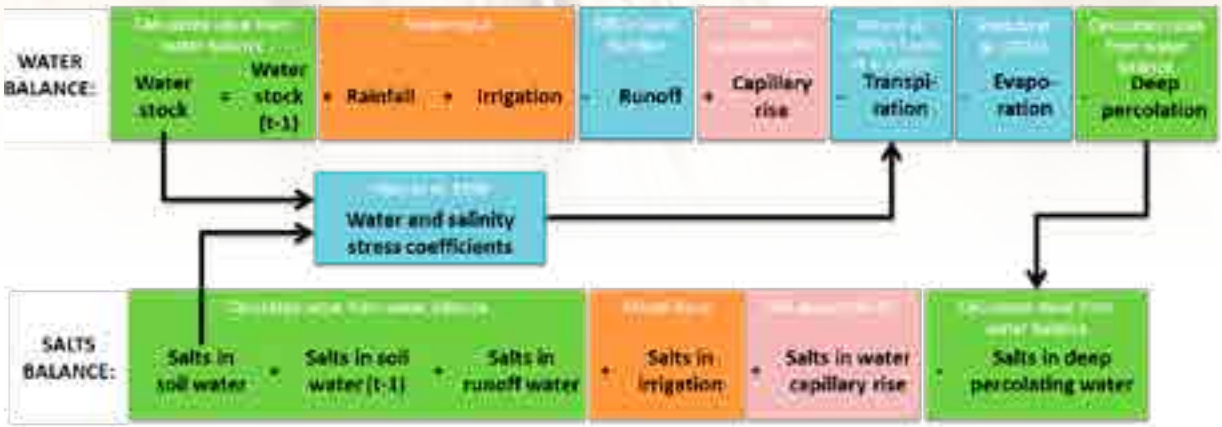

Figure 1: The modular structure and main formalisms for the E.T. model. NRCS: Natural Resources Conservation Services.

2.2 Model validity domain

The E.T. model is based on old and robust formalisms having a large domain of validity. For example, surface runoff is estimated based on the Natural Resources Conservation Services (NRCS) Curve Number (Mishra and Singh 2003), accounting for soil type, land use, hydrologic conditions, and antecedent moisture condition. Nevertheless, the model should be modified in situations where soil has a very low saturated conductivity or a shallow aquifer. Regarding the crop, the E.T. model is operational for citrus because the transpiration estimation is based on a recent development specific to citrus crops (Taylor et al. 2015). However, the model is potential valid for all crops if the leaf resistance is adjusted accordingly (refer to Allen and Pereira (2009) and Steduto et al. (2012)). Regarding the technology (agricultural practices) validity domain, this model is tailored for localised irrigation modes. The model has to be adjusted to model surface irrigation.

2.3 Model testing

The model was applied to a perennial mandarin crop grown in Morocco, over seven crop cycles, from planting in October 2007 to April 2015. Most data were primary data collected from a mandarin farm located in central Morocco, owned by “Les Domaines Agricoles”. Table 1 shows a selection of key model input and parameter values and data sources. A few data gaps in climate data were filled following specific rules depending on the climatic parameter. The output variables of the model were compared to field measurements (from bibliography and case study) and water inventory databases (Water Footprint Network; Pfister et al. 2011; Pfister and Bayer 2014). The sensitivity of the E.T. model outputs was assessed against model parameter range testing, based on realistic values rather than arbitrary values for initial conditions of soil water stock (S(i)) and soil water salinity ($EC_{soil\ water}(i)$), and the average fraction of Total Available Water (TAW) that can be depleted before a water stress occurs, namely “p”, (p is crop-specific, and defined in Allen et al. 1998). The E.T. model was used to simulate different scenarios of practice through the use of different input data. We simulated: a larger wetted zone by irrigation, deeper rooting depth for adult trees, bigger (+20%) and smaller (-50%) tree canopy size and plantation density, and a land use type less favourable to runoff through a smaller curve number.

Table 1: Selected key model input variables and parameters, average values for the case study, data sources and assumptions

Input variable/ parameter	Description	Average values for the different mandarin cropping phases[1]			Data source
		Non-productive	Growing yield	Full production	
S	initial soil water stock [mm]	Field capacity			Farm antecedent practices
$EC_{soil\ water}$	initial soil water electrical conductivity [$dS.m^{-1}$]	1.46			Farm soil analysis
p	fraction of TAW that can be depleted before water stress occurs	0.5			Allen et al. (1998)
%G	ground cover fraction of the tree canopy [%]	20	50	70	Allen et al. (1998) and Taylor (2015)
h	mean height of the vegetation [m]	2	2.5	3	Observation at farm and Allen et al. (1998)
r_{leaf}	mean leaf resistance [$s.m^{-1}$]	316* ET_o-61			Citrus orchards : Taylor et al. (2015)
I(t)	Irrigation water [mm]	Total irrigation: 6053			Daily farm records. Data gap: Monthly irrigation disaggregated
EC_{iw}	Electrical conductivity of irrigation water [$dS.m^{-1}$]	1.258	1.258 - 1.165	1.187	Irrigation water analysis
ET_o	reference evapotranspiration [mm]	Total ET_o : 15264			Weather station at farm. Data gap: based on average ET_o of known years, or monthly ET_o disaggregated
P(t)	rainfall [mm]	Total rainfall: 1566			Weather station at farm. Data gap: monthly P disaggregated based on rainy days per month
Yield	Total crop yield [$ton.ha^{-1}$]	249.5			Farm records : yield from 2008 to 2015

[1]Based on the yield, cropping phases are split into a non-productive [0 to 2 years], growing yield [3 to 6], and full production [7 to 25] phase. Full production is when the maximum yield is reached.

2.4 Model application for water use impact assessment

The impacts of water use for mandarin cultivation were assessed with the water availability indicators defined by Boulay et al. (2011a&b). This is the most scientifically-sound method since it accounts for both water quantity and quality effects on water deprivation, and proposes characterisation factors specific to the water compartment for withdrawal and release. Impacts were expressed in m^3_{eq} deprived per ton mandarin cultivated. The model outputs served as water elementary flows for the mandarin cultivation stage, and were multiplied by the corresponding characterisation factors. The inventory water flow requirements for applying this method are presented in Figure 2.

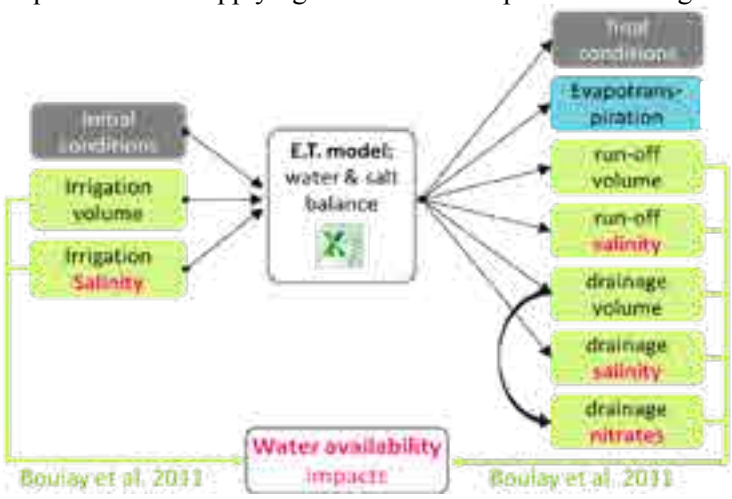

Figure 2: E.T. model integration for water availability impacts calculation: input and output water flows are converted to impacts on the environment following Boulay et al. (2011)

We first compared water inventory flows estimates of the E.T. model, with databases (Pfister et al. 2011; Pfister and Bayer 2014). Then, we compared water deprivation impact results based on different inventory methods.

3. Results and discussion

3.1. Model testing

The sensitivity of the model outputs to initial conditions and the parameter p (fraction of TAW that can be depleted before a water stress occurs) was low, which demonstrated the robustness of the E.T. model. For example, for p values ranging from 0.1 to 0.8, the model outputs were slightly affected: the maximum variation observed was for the actual evapotranspiration originating from rainfall ($ET_{a\ green}$) which varied from -5.4% to +2.5%.

The estimations of evaporation and transpiration from the E.T. model compared well with literature and measurements on citrus. For example, Villalobos et al. (2009) measured average evapotranspiration and soil evaporation for a mandarin orchard cultivated in the south of Spain in August and in May at 2.6 and 2.1 $mm.day^{-1}$ while corresponding E.T. model estimates (using previous 3-year data) were 2.8 and 2.0 $mm.day^{-1}$ respectively.

Figure 3 shows that the E.T. model allowed the simulation of scenarios of agricultural practices: land use type less favourable to runoff resulted in a smaller runoff, a bigger tree canopy size and plantation density resulted in greater transpiration, a deeper rooting depth for adult trees resulted in a smaller deep percolation, and a larger wetted zone by irrigation resulted in a greater evaporation.

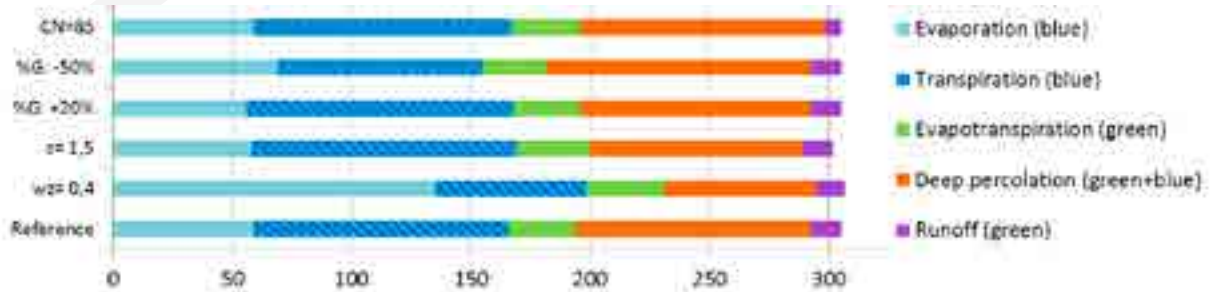

Figure 3: Water flows estimated with the E.T. model (in $m^3.ton^{-1}$ mandarin cultivated) for different scenarios. Blue and green refer to the origin of water (blue from ground water, green from precipitation). The input variables tested are: CN= curve number (for the runoff calculation), %G= percentage of ground covered by vegetation, z= rooting depth, wz= wetted zone by the irrigation. The reference scenario was: CN=91, z=0.4, wz=0.1.

We used the model salinity outputs for two purposes: (i) estimating the reduction of evapotranspiration due to salinity stress and (ii) estimating the average amount of salts percolating toward the aquifer in deep percolating water. If saline stress was not accounted for, the transpiration was overestimated by 22.3%. This shows the relevance of accounting for saline stress when estimating crop water consumption. The E.T. model estimated an average salt concentration of deep percolating water of 1.88 $g.L^{-1}$.

Comparing the variation of model outputs with the variation of model inputs showed that all water flows were very sensitive to the basal crop coefficient value (describing plant transpiration); this highlighted the importance of an accurate calculation of this “crop transpiration coefficient” specific to crop and practices.

This first testing of the model demonstrated the discriminating power of the model, its low sensitivity to key parameters, and the importance of the crop coefficient value. Nevertheless, beyond

this first testing of the model and its robustness, a proper sensitivity analysis and a Monte Carlo analysis would be warranted in future work, notably to assess the effects of uncertainty interactions and cumulative effects. In particular, we should investigate the models discriminating power regarding the site context (in particular the soil texture which is influencing several parameters), but also we should test the use of default rainfall data from the Climwat database (FAO 2010).

3.2. Model data requirements

Regarding the additional efforts for running the model, in comparison with an LCA study reporting only water volume, the additional effort required for data collection is reasonable since most farmers record irrigation supply volume, at least on a monthly basis. Cross-checking monthly irrigation volumes with irrigation frequency allows data to be disaggregated at a daily time-scale. Other critical data is on water quality, as highlighted by Boulay et al. (2015), but this is the weakest aspect of methods addressing degradative use of water. When water quality analyses are not available, global datasets can be used such as GEMStat (UNEP 2009). Other E.T. model input data (climate, soil…etc) should preferably be primary data, but default values can also be used if necessary (default data sources are provided in Payen, 2015).

3.3 Model limitations and improvement perspectives

It is important to notice that the salt balance is a rather simplified approach since several mechanisms are neglected including precipitation and dissolution of salts, and salt uptake by plants. In addition, salt conversion factors from electrical conductivity to concentration are only an approximate equivalence factor (USDA-NRCS 2015). The effect of salinity on plant nutrition is not accounted for since this would require a nutrient budget and the modelling of complex interactions between salinity, nutrient, water and the crop.

Regarding the stresses of the crop, we only considered water and salinity stresses. Stress coefficients are approximate estimates of salinity and water impacts on evapotranspiration. In particular, evapotranspiration might be underestimated at high salinity levels. Thus, the model could be improved regarding the inclusion of salinity stress and evaporation mechanisms.

The stress coefficient calculation should be revised to account for: (i) the effect of climate and growth development stage, as it is implemented in the Aquacrop model (Raes et al. 2012), (ii) the effect of salinity on the water stress threshold since salinity can lower the minimum soil water content at which a crop will start to be negatively affected (Raes et al. 2012), and (iii) the possible non-linear curve response factor to stresses.

3.4 Comparison of model outputs with water databases

Since water databases do not provide information about water quality or water released, the only E.T. model outputs we could compare with water databases were $ET_{a\ blue}$, and $ET_{a\ green}$. We compared the total blue water consumption ($ET_{a\ blue}$) of the mandarin cultivation stage calculated with the E.T. model and with Pfister et al. (2011) and Pfister and Bayer (2014) databases (providing an estimation of water consumption by crop at a country scale). The lowest $ET_{a\ blue}$ estimate was from the Pfister and Bayer database (2014) at 149 $m^3.ton^{-1}$, and the highest estimate was from the Pfister database (2011) at 237 $m^3.ton^{-1}$, whereas our estimate with the E.T. model (accounting for salinity and water stresses) was 181 $m^3.ton^{-1}$.

3.5 Water impact results

The E.T. model allows the calculation of water impacts using Boulay's approach, which is not possible with water databases. The water availability impacts score was 189 m^3_{eq} per ton mandarin. This water availability indicator addresses both consumptive and degradative use. However, the quality degradation of deep percolating water originating from rainfall was not accounted for in our implementation of the Boulay's method because it relies on the estimation of the evapotranspiration of a "reference state" if the crop was not in place. The rainfall and irrigation water partitioning (so-

called green and blue waters) is arbitrary and fails to properly represent the water cycle. It constitutes an important drawback in the assessment of water use impacts. Additionally, an analysis of the characterisation model from Boulay et al. (2011b) reveals that the ground water specific characterisation factors (0.565) may be underestimated for this area in Morocco. Indeed, the reliability of ground-water specific characterisation factor is questionable since data on groundwater resources do not have a sufficient quality in existing hydrological models (on which the characterisation factors are based) (Boulay et al. 2015).

4. Conclusions

The E.T. model was developed to fill a gap, i.e. the lack of a simple water and salt flow model for perennials, and to meet an objective of determining the inventory of field water and salt flows for the LCA of a cropping system. The E.T. model is a modular and original integration of old and robust concepts for water balance with more recent modules for transpiration estimation. This is a tailored model rather than a new model. Its advantages are its simplicity, transparency and flexibility. It meets the requirements of estimating evaporation, transpiration, deep percolating water and runoff water accounting for possible water and salinity stresses, and based on effective irrigation supply and cropping system characteristics. It also provides information about the quality of water flows via salinity of deep percolating water and the soil water stock. When applied to a perennial crop (mandarin grown in Morocco), the E.T. model outputs compared well with literature and measurements, and allowed the simulation of scenarios of agricultural practices. Its validity domain (in terms of agricultural practices and natural site characteristics (aquifer depth, salinity level)) and accuracy could be extended based on recommendations provided in this work. The E.T. model outputs can serve as water inventory elementary flows to assess the impacts of water use and when LCIA models will be available, to evaluate salinisation impacts (Payen et al. 2016). The use of E.T. for estimating field water and salt flows will ease the application of water use impact assessment methods, including the method addressing both consumptive and degradative water use (e.g. Boulay et al. 2011).

The most scientifically-sound result for water use impacts is the one based on water flows estimated with the E.T. model (accounting for water and salinity stresses), and characterised with Boulay et al. (2011a and b). However, an analysis of the Boulay's characterisation factors showed that developing characterisation factors specific to the water source (surface or groundwater) is very relevant, but their current quality is hampered by the lack of good quality data on groundwater resource state in the global hydrological models they use. Thus, the E.T. model is a relevant tool for the inventory of water flows, but it is important to keep in mind that there are still improvement margins for the impact assessment of water uses.

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6. References

Allen, R.G., and Pereira, L.S. 2009. Estimating crop coefficients from fraction of ground cover and height. Irrig Sci 28. pp 17–34.

Allen, R.G., Pereira, L.R., Raes, D., and Smith, M. 1998. FAO Irrigation and Drainage Paper No. 56 - Crop Evapotranspiration: guidelines for computing crop water requirements. FAO, Rome, Italy. p 300.

Batjes, N.H. 2006. ISRIC-WISE derived soil properties on a 5 by 5 arc-minutes global grid (version 1.1).

Boulay, A-M., Bouchard, C., Bulle, C., Deschênes, L., and Margni, M. 2011a. Categorizing water for LCA inventory. Int J Life Cycle Assess 16. pp 639–651.

Boulay, A-M., Bulle, C., Bayart, J-B., Deschênes, L., and Margni, M. 2011b. Regional characterization of freshwater Use in LCA: modeling direct impacts on human health. Environ Sci Technol 45. pp 8948–57.

Boulay, A-M., Motoshita, M., Pfister, S., Bulle, C., Muñoz, I., Franceschini, H., and Margni, M. 2015. Analysis of water use impact assessment methods (part A): evaluation of modeling choices based on a quantitative comparison of scarcity and human health indicators. Int J Life Cycle Assesment 20. pp 139–160.

FAO. 2010. CLIMWAT 2.0 for CropWat. [Online] Available from www.fao.org/nr/water/infores_databases_climwat.html/ Accessed 1 July 2015

FAO/IIASA/ISRIC/ISS-CAS/JRC. 2012. Harmonized World Soil Database (version 1.2).

Frischknecht, R., Jungbluth, N., Althaus, H-J., Bauer, C., Doka, G., Dones, R., Hischier, R., Hellweg, S., Humbert, S., Köllner, T., Loerincik, Y., Margni, M., and Nemecek, T. 2007. Implementation of Life Cycle Impact Assessment Methods. Swiss Center for Life Cycle Inventories, Dübendorf. p139.

Mishra, S.K., and Singh, V.P. 2003. Soil Conservation Service Curve Number (SCS-CN) Methodology. Springer Netherlands, Dordrecht. p 277.

Mitchell, T.D., and Jones, P.D. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Climatol 25. pp 693–712.

Nemecek, T., Bengoa, X., Lansche, J., Mourin, P., Riedener, E., Rossi, V., and Humbert, S. 2015. Methodological Guidelines for the Life Cycle Inventory of Agricultural Products. World Food LCA Database (WFLDB). Version 3.0, July 2015. Quantis and Agroscope, Lausanne and Zurich, Switzerland. p 79.

New, M., Lister, D., Hulme, M., and Makin, I. 2002. A high-resolution data set of surface climate over global land areas. Clim Res 21. pp 1–25.

Payen, S., Basset-Mens, C., Colin F., Roignant P (n.d.) Inventory of field water flows for agri-food LCA: critical review and recommendations of modelling options. International Journal of Life Cycle Assessment (Submitted)

Payen, S., Basset-Mens, C., Núñez, M., Follain, S., Grünberger, O., Marlet, S., Perret, S.R., and Roux, P. 2016. Salinisation impacts in Life Cycle Assessment: a review of challenges and options towards their consistent integration. Int J LCA 21. pp 577–594.

Payen, S. 2015. Toward a consistent accounting of water as a resource and a vector of pollution in the LCA of agricultural products: Methodological development and application to a perennial cropping system. PhD thesis, University of Montpellier, Montpellier, France. p 179.

Pfister, S., and Bayer, P. 2014. Monthly water stress: Spatially and temporally explicit consumptive water footprint of global crop production. J Clean Prod 73. pp 52–62.

Pfister, S., Bayer, P., Koehler, A., and Hellweg, S. 2011. Environmental impacts of water use in global crop production: hotspots and trade-offs with land use. Environ Sci Technol 45. pp 5761–8.

Pfister, S., Koehler, A., and Hellweg, S. 2009. Assessing the Environmental Impacts of Freshwater Consumption in LCA. Environ Sci Technol 43. pp 4098–4104.

Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E. 2012. AquaCrop version 4.0 - Chapter 3: Calculation Procedures. FAO, Land and Water Division, Rome, Italy. p 125.

Steduto, P., Hsiao, T.C., Fereres, E., and Raes, D. 2012. FAO Irrigation and Drainage Paper No. 66 - Crop yield response to water. FAO, Rome, Italy. p 505.

Taylor, N.J., Mahohoma, W., Vahrmeijer, J.T., Gush, M.B., Allen, R.G., and Annandale, J.G. 2015. Crop coefficient approaches based on fixed estimates of leaf resistance are not appropriate for estimating water use of citrus. Irrig Sci 33. pp 153–166.

UNEP. 2009. Water programme GEMStat – Global Environment Monitoring System (GEMS) [Online] Available from http://www.gemstat.org / Accessed 1 August 2015.

USDA-NRCS. 2015. Natural Resources Conservation Services - Water Quality Tests, Units of Measure, and Conversions - Appendix MT-61. [Online] Available from http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mt/home/?cid=nrcs144p2_057683/ Accessed 1 September 2015.

Villalobos, F.J., Testi, L., and Moreno-Perez, M.F. 2009. Evaporation and canopy conductance of citrus orchards. Agric Water Manag 96. pp 565–573.

Water Footprint Network. 2015. Water Footprint Statistics (WaterStat) [Online] Available from http://waterfootprint.org/en/resources/water-footprint-statistics/ Accessed 1 July 2015.