Final EURO-AGRIWAT conference

Water Footprint of agricultural products: progress, challenges and solutions

7-9 March 2016

Wageningen

BOOK OF ABSTRACTS

The Final EURO-AGRIWAT conference was hosted by

Wageningen University and Research

and supported by the

SENSE Research School for Socio-Economic and Natural Sciences of the Environment

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The final Conference of COST - ES1106

On March 7, 8 and 9, 2016, the AgriWat Conference was held as a closure of the COST-action ES1106 about Water footprints (WF). The conference was organized in collaboration with the Research School for Socio-Economic and Natural Sciences of the Environment (SENSE).

The COST Action ES1106 EURO-AGRIWAT focuses on the assessment of water footprint (WF) and virtual water trade (VWT) of key food and no-food agricultural products, including their uncertainties, as well as scenarios concerning WF and VWT under future climatic conditions. The use of advanced tools and data such as remote sensing, updated climatic databases, climatic projections/scenarios and agrometeorological models represents the base of the activity. The use of such instruments will allow a detailed analysis of interactions between crops, climate and management that will be taken into account in the WF assessment. An important component of the Action will be the preparation and dissemination of recommendations and guidelines for enabling a more efficient water resource management in relation with agricultural activities under climate change and variability. The framework of a COST Action represents the most suitable way for facing the outstanding and multi-faceted problem of sustainable water use, being characterized by a non-competitive and interdisciplinary environment of high scientific level. These features will allow a collaboration between scientists and stakeholders and the development of common strategies to broaden the available research expertise.

The Conference was held in Wageningen on the Campus of Wageningen University and Research. There were about hundred participants from a broad public, ranging from research to medium and large private companies.

During the first day the focus of presentations was on concepts and critics of WF.
During the second day the focus was on solutions to WF-concepts and inefficient unsustainable water use.
On the last day, March 9, 2016, excursions were organised.
For more details about the programme see annex A.

The next chapters give an overview of the content of the presentations.

More information about the final conference, including the PDFs of the presentations, can be found at the conference web site: www.agriwatconference.org.

Synthesis AgriWat Conference 'Water Footprint of agricultural products: progress, challenges and solutions'

Wageningen, 7-9 March 2016

This introduction provides a synthesis of progress, challenges and solutions discussed during the conference, with a summary of the plenary sessions. More information about presentations in different sessions can be found in the remainder of this Book of Abstracts.

Plenary sessions

During a first plenary session) the scene was set by Anna Dalla Marta (Chair of COST ES1106 EURO-AGRIWAT) who provided an overview of the COST Action. Then Arjen Hoekstra presented the progress made since he introduced the water footprint concept in 2002. Hoekstra's overview was followed by reflections of Elías Fereres, who highlighted the main complexities in the relation between water and food production.

From this session we learned that Water Footprint Assessment (WFA) serves well as a communication tool, and may therefore support solutions towards sustainability, efficiency, equitability and resource security (this was supported by many of the presentations in the sub-sessions). Since 2002, the range of products and processes and geographical areas that have been subject to WFA has widened considerably and links have been established with other fields including Life Cycle Analyses (LCA). Criticism on WFA includes that on definitions of the grey water footprint and a lack of contextual relativism. Fereres pointed out that progress could be found in better applying the physiologic basics from agronomy and that detailed field observations and experiments are a necessity to estimate evapotranspiration (ET) and calibrate simulation models. In many studies presented in the sub-sessions models were used to evaluate WF, including effects of projected climate change (challenge: this requires proper calibration e.g. using data from FACE experiments). Next to emphasising the need for reducing consumptive water use of crops, more attention needs to be devoted to increasing yields to reduce WF.

In a following plenary session the main findings of four working groups of the COST action were presented. WF estimations (using different models) for major cereal crops showed significant variation. An important reason for the differences is the use of Evapotranspiration or Transpiration only. Similar to crop models, the uncertainty of estimates derived from remote sensing techniques is still high, and needs to be improved. It was stated that when virtual water trade is assessed for specific case studies, the level of detail allows for suggestions to improve water policies and management. However, some aspects of sustainability have been neglected in WFA so far.

On the second day a plenary session shed some light on possible pathways to improving WFA by discussing solutions. Martin van Ittersum presented the approach used for the Global Yield Gap Atlas. He showed that actual yields are often much lower than the potential yield that can be obtained. Although important findings on increasing water productivity have been done, protocols are needed to make local assessments useful at larger scales. Huub Rijnaarts followed up by highlighting the potential of improving water cycles and increasing the recycling of water and water-use efficiency, mostly in an urban context. Then, Jay Lund presented how California is quite resilient to droughts. Although much less water was used, economic losses remained limited. He also stressed that portfolio management (rather than focussing on single strategies) is needed to tackle problems effectively.

In a closing plenary session the strengths and weaknesses of WFA were highlighted by Ruth Matthews (of the Water Footprint Network) and Gerardo van Halsema. Matthews stressed the value of WFA as a communication tool that serves as an eye-opener to companies that now increasingly aim at improving the water-use efficiency along the entire supply-chain. For WFA to be useful it should include a response strategy formulation. Matthews explained that a lot remains to be done to improve grey WF assessment. Critical remarks were made by Gerardo van Halsema, who pointed out that different yield levels may result in the same water productivity (WP; inversely proportional to WF), as this relation is a linear one. Van Halsema also showed how inadequate interpretations of remotely-sensed data for WF assessments may lead to unjust conclusions, especially when combining data (for yields) representing different spatiotemporal scales.

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First Plenary Session 7th March 2016: 9.30-11.00

Anna Dalla Marta :

Objectives and conclusions Assessment of EUROpean AGRIculture WATer use and trade under climate change

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Water is a resource and water management is one of the hot topics globally and will continue to be so in Europe particularly under climate change.
In particular, increasing world population, changes in standard of living and the consequent increasing need for food, feed and bio-energy will require more efficient agricultural management practices, i.e. sustainable intensification of cropping systems. This concerns in particular irrigation. In fact, under climate change, water scarcity is likely to impose limits not only to irrigation enlargement but also to the already existing systems in many European countries. In this respect, the concept of water footprint acquired a global recognition.
The WF, as a quantitative indicator communicating simple and effective information on water consumption along food chains, has gained a strategic role in rising awareness on the importance of water and its indirect consumption. The concept of WF is now part of the common language and it has been applied in the meantime in many studies. However, a coordinated activity systematically addressing all phases of the water footprint assessment at the European scale, under present and future climatic conditions, was still missing. In this context, the idea of a dedicated COST Action took form, thanks to the collaboration among an international group of scientists working on agriculture, agrometeorology, crop modelling, water resource management, hydrology, and socio-economy.
The main aim of Action ES1106, EURO-AGRIWAT, was to bring together the expertise of those different European research groups for an inter-disciplinary cooperation to provide recommendations and guidelines to enable a more efficient water resource management in relation with agricultural activities. Specific objectives of the Action were:

1) To assess the water footprint of the main food and no-food crops cultivated in Europe for both irrigated and rain-fed systems
2) To investigate the concept of virtual water trade with the regards to national and regional water efficiency use in agriculture in Europe
3) To evaluate tools (e.g. agrometeorological and crop models) for assessing climate change impacts (including elevated CO_2) on the local/regional WF
4) To tackle the question of how data assimilation (including agrometeorological, climatic and remote sensing information) can contribute to assess the WF under various agroclimatic conditions in Europe.

The planned activity was carried on thanks to the scientific collaboration of 4 Working Groups focusing on WF, virtual water trade, sustainability and on the effective use of remote sensing in WF related studies. The activities last for 4 years and significant results have been achieved, among which, peer-reviewed scientific publications, international workshops, training schools, and reports.

Arjen Hoekstra :

Water footprint assessment: an evolving research field

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While many regions on earth are blessed with plenty of water to provide for life and growth, recent research shows that 4 billion people face severe water scarcity for at least one month per year. Regional climate conditions are obviously a key factor for water scarcity – and climate change may cause even more water security challenges in the future – but in order to understand the complex economy of water consumption, water shortages and pollution, the problem needs to be considered from a global perspective. Many countries have significantly externalised their water footprint, importing water-intensive goods from elsewhere. This puts pressure on the water resources in the exporting regions, where too often mechanisms for wise water governance and conservation are lacking. Many water problems are thus closely tied to the structure of the global economy. Fair allocation of limited water resources over competing demands is one of the great challenges of the coming century. Consumers, governments, companies and investors are all essential players to move in a direct of more sustainable use of our most precious resource.

Water Footprint Assessment has emerged as a new interdisciplinary field of research, focussing on the analysis of water use and scarcity in relation to production, consumption and trade patterns, and the study of the role of governments, companies, investors and civil society in addressing the problem of unsustainable, inefficient and inequitable water footprints. The field typically analyses water use in relation to demand for food, energy and other needs and analyses how goals regarding sustainable water use can be translated into coherent agricultural, energy, tax and trade policies. Topics that will be hot topics for future research include the study of water footprint caps per river basin (to ensure that water consumption and pollution remain within maximum sustainable levels, accounting for environmental flow requirements), the development of water footprint benchmarks for water-using processes and products (based on best available technology and practices), the use of remote sensing to estimate water footprints, water availability and water scarcity real-time and at a very high spatial resolution, the development of coherent low-carbon / low-water food and energy scenarios, and the integration of the different footprints into a coherent set of environmental footprint indicators.

Elías Fereres :

Addressing the complexities in the relation between water and food production: avoiding too simplistic views, and future prospects.

Physiological and agronomic determinants of crop yield response to water

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Crops consume large amounts of water as determined largely by the environments in which they are grown. The introduction of the water footprint concept should have conveyed this reality to the general public; nevertheless, urbanites are often surprised by the magnitude of crop consumptive use, as exemplified by the barrage of media articles criticizing the excessive consumption of almonds in the recent California drought. Pressures from other sectors of society and water scarcity due to periodic droughts will force farmers to optimize the use of water in crop production.

All optimization approaches must be based on knowledge on the yield response to water and, in turn, on the physiological and agronomic factors determining such response. The ultimate goal is to be able to accurately assess the economic returns of using different amounts of irrigation water and to evaluate the risks/rewards of seeking/acquiring additional supplies in the event of a drought. The presentation will review the state of the art in predicting crop yield response to water using empirical and mechanistic approaches, and will analyze the role of key physiological and agronomic processes in improving the efficiency of water use in crop production in the future.

Second Plenary Session 7th March 2016: 11.30-11.50

Christian Kersebaum :

Assessing the uncertainty of model based water footprint estimation using an ensemble of crop growth models

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Keywords: Water footprint, crop model, climate change, ensemble modelling

The Water Footprint (WF) of a crop is defined as the volume of water consumed for its production, where green and blue WF stand for rainfed and irrigation water usage, respectively. Crop productivity and water consumption together form the basis to calculate the water footprint of a specific crop. While under current climate conditions calculated evapotranspiration is related to observed crop yields to calculate WF, the assessment of WF under future climate conditions requires the simulation of crop yields as well, which may add further uncertainty. Climate change including increasing CO_2 concentration of the atmosphere will affect crop growth as well as soil water dynamics. Agricultural production systems are very vulnerable to a potential decrease in water availability. The impacts of climate change (increasing temperatures, shifts of seasonal precipitation and decreasing summer rainfall) could cause water limitations in many areas of Europe. A change of currently estimated water footprint values is expected under climate change. However, it is not clear, how far the above mentioned negative impacts of a changing climate can be compensated by the positive effects of increasing [CO_2].

To assess the uncertainty of model based assessments of WF an ensemble of different crop models was applied to field data sets from 5 locations from across Europe. Only limited data were made available to allow only a rough calibration, which corresponds to a typical situation for regional assessments, where data availability is limited. Up to 8 models were applied depending on the data set. In the comparison we focussed on cereal crops, mainly winter wheat.

The coefficient of variability for the simulated actual evapotranspiration (ETa) between models was in the range of 13-19 %, which was higher than the inter-annual variability. However, simulated grain yields showed a higher variability between models in the range of 16-24 %. Models responded differently to elevated CO2 for experimental data from a FACE experiment, especially regarding the reduction of water consumption due to lower stomatal conductance under elevated CO2. Overall, the variability of calculated WF between models was in the range of 26-36%. Uncertainty of yield predictions contributes more to this variance than the estimation of water consumption.

Christos Zoumides :

Virtual water trade: an overview of applications and implications

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Virtual water trade refers to the hidden or embedded flow of water when commodities are traded from one location to another. The concept of virtual water trade was introduced by Prof. Tony Alan in the mid-1990s. Initially, the discussion on virtual water trade focused on water-scarce countries, which – as suggested by the notion - could achieve water security by importing water-intensive products instead of producing all water-demanding products domestically. Ever since the concept has evolved and gained overwhelming attention, both in the scientific community and in water policy debates. As a scientific and analytical concept, virtual water trade represents a tool to quantify, describe and assess the relationship between global trade and water use, especially as regards food commodities. Typically, the international food trade is translated into a corresponding virtual water trade using water footprint values per commodity and country in a given period of time. The analysis of virtual water trade fluxes reveals countries which import virtual water to sustain their population and countries which are net exporters of virtual water, i.e. those that produce more than the domestic demand. In this respect, the virtual water concept provides a novel framework to quantify and study the use of water in agriculture and the water exchanges embedded in food trade. Many scientific contributions at the global and national level have highlighted the enormous volumes of water needed for the production and trade of food products, using different methodological and analytical approaches. This presentation provides a brief overview of virtual water applications, with reference to key studies and their findings.

Besides the quantification interest, the virtual water trade concept became part of water policy and management debates, on whether the concept can be practically implemented to induce the synergies between trade strategies and water use efficiency from the local to the global level. Thus, the presentation will outline the main arguments as an opening to the discussion that will follow in the virtual water trade session, which aims to address the following questions:

- Does the virtual water trade practically contribute to improved water governance, food and water security?
- Does the virtual water trade concept contribute to awareness-raising and water savings through diets modification?
- What structures are required to enable sustainable and equitable virtual water trade?

Filiberto Altobelli :

Sustainability of agriculture water footprint: a multidisciplinary issue

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The concept of sustainable development was born in the early 80s on the basis of considerations relating to the relationship between society and environment. Today this concept is rooted in the political dialogue in the world with increasing understanding of the interactions between social systems and environmental systems. The report of the Brundtland Commission defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Economic development, therefore, is assessed not in absolute terms but in relation to the ability to contribute to the wellbeing for future generations.

Starting from the recognition of the role of natural capital in sustainable development, in recent years a new economic concept of Green Economy has been introduced by the UNEP (2011), defined as the economy that determines the growth of wellbeing and social equity, reducing environmental risks and ecological scarcities.

Europe is one of the major users of fresh water in the world when referenced using the indicator of water footprint for its estimation. Furthermore, it is one of the largest importers of virtual water in the world. Therefore, the sustainability of water resources in Europe cannot be separated from an afterthought of agricultural development, which is well known coming into play in the use of water resources. Responsibilities must be investigated among all the actors, whether institutional or private consumers.

The adoption of the indicator of the water footprint could be very useful in the future, having spread and having an easy understanding of both institutional actors and consumers. But yet, there are many aspects that are still little considered, as that of estimating an indicator of sustainability, able to integrate economic, environmental and social aspects.

Working group 3 addressed this issue through the adoption of a decision-making conceptual framework for the assessment of a sustainability index, and the development of a methodology for assessing and comparing different agricultural productions and farming systems in terms of economic and social outcomes for a given volume of water.

Leonidas Toulios :

Using remote sensing for assessing water footprints

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Remote sensing has long been a useful tool in global applications, since it provides physically-based, worldwide and consistent spatial information over space and time. Nowadays, a new era in earth observation has been dawned and series of very high spatial, spectral and temporal resolution remote sensing data are now available, based on new satellite sensors and satellite constellations. Such satellite-derived raw data and ready products in connection with the increased computing power, positioning precision and communication advances are now identified and selected for detailed analyses.

Recent papers initiated the study of the potential of using these data obtained from remote sensing, in the field of water cycle and water management, for Water Footprint studies and green and blue water assessment.

In the frame of COST action ES 1106, the analysis of the role of satellite data in the suitable models and indices related to WF assessment was among the main aims. Several tasks were initiated and integrated focusing on the investigation of the potential of remote sensing data in WF assessment. An overview of the agricultural WF estimation on related regional studies including remote sensing, in the COST ES1106 member countries was initially reported. Furthermore, with these studies, the main inputs for green and blue WF estimation were identified, the computational remote sensing methodologies were reviewed and described, as well the main characteristics of the spectral data and the main vegetation indices were drawn up. The assessment of the required spatial, spectral and temporal resolution of satellite data for the analysis of WF and the assessment of the most appropriate set of vegetation indices and biophysical variables in the context of a cost-effective solution to monitor agricultural water, using satellite data, were among the main tasks too.

Based on the above reports it is concluded that existing methods have calculated the WF using data from national statistics, reports and climatic databases. Monitoring crops in an appropriate space and time scale may provide better estimates of blue and green water use. Several aspects have been identified which may be estimated and show improvement with the use of remote sensing techniques on different scales: retrieval of actual evapotranspiration, determining irrigated areas, quantification of precipitation, mapping of land use and vegetation characteristics, estimation of surface runoff, and quantification of water storage. The combination of the different spectral inputs provides limitations, since the data differ in terms of spatial coverage, spatial and temporal resolution and availability and consistency between data.

Session I - Assessment of crop water footprints under present and future climatic conditions (C3015)

Convener: Christian Kersebaum

Session I - Assessment of crop water footprints under present and future climatic conditions, 7th March 2016, 14.00-15.30

Anne Gobin :

Variability in the water footprint of arable crop production across European regions

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Keywords: water footprint, variability, arable crop production, European regions

The water footprint concept has created great awareness of sustainable water use and consumption. Applied to crop production, the green water footprint (WF) relates to rain water consumed, the blue WF to irrigation water consumed and the grey WF to water required for diluting agri-chemicals. We focussed on the green and blue WF and its variability for major arable crops in Europe.

Crop growth and yield are affected by water availability and water stress during the season. Crop evapotranspiration and dry matter yield were modelled using FAO's water balance model Aquacrop with reference evapotranspiration based on the assumptions by Allen. Weather input was collected for around 50 meteorological stations for the period 1992-2012. Soil, crop characteristics and field management for experimental fields enabled model calibration. Calibrated model runs were subsequently conducted for wheat, barley, grain maize, potato and sugar beet where applicable, and on the dominant soils for a particular region. The green and blue water footprints were calculated by dividing the total volume of green and blue water use during the growing season by the quantity of the production, respectively.

The results demonstrated that the WF of cereals is larger than the WF of tuber and root crops, and that within each crop group there is a difference between different crops. This difference depends largely on the proportion of marketable produce to biomass produced per surface area. The calculated WF compared favourably with internationally available values, but is also subject to a large variability owing to both crop water use and yield differences between years, soils, and even more so between regions across Europe. In general, the drier the year, soil or region, the larger the water footprint. The WF for wheat, for example, can be up to five times larger for dry regions in southern Europe as compared to high yielding north-western European regions.

Despite the demonstrated large variability, the water footprint is a policy-relevant concept and measurable indicator that supports European water governance.

Session I - Assessment of crop water footprints under present and future climatic conditions (C3015)

Convener: Christian Kersebaum

Pavol Nejedlik :

Water use efficiency and water footprint of selected crops A case study - Slovakia

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Keywords: yields, rainfed production, water use efficiency, water footprint

To study water use efficiency and to calculate the water footprint a region with the most intensive agricultural production in the country was selected and three main crops were investigated. Generally, area under cultivation in Slovakia occupies about 1.9 millions of hectares and is shrinking as well as the irrigated area which went down from about 350 thousands hectares to one 100 thousands hectares. The production of the main crops relies mostly on rainfed production which balances from year to year in the range +/- 60% in district averages.

Spring barley, winter wheat and corn were investigated during the period 1997-2012. There are more data about both the real yields and meteorological data available but due to the change in the political districts in middle nineties the statistics of the seeded area and yields couldn`t be prolonged back before 1996. The investigated area is located in south west Slovakia and covers about ten thousand square kilometers. All the area belongs to the northern part of Danubian lowland and is flat with the elevation range about 115 - 190 m a.s.l.

Daisy model and the data from four meteorological stations from the area were used to model the yields of above mentioned crops in in the period of 1997-2012 and these were compared to the observed yields available at the county and districts level. The simulation was done for five different soil data representing the soils which are most frequent in the area (haplic chernozems, endofluvic chernozems, haplic phaeozems, haplic fluvisols, fluvisols siltic and clayic). Further to that the yields also for the period 1961-1996 were simulated. Based on this database the water use efficiency and the water footprint were calculated.

The results showed higher level of the water footprint with the real yields of the crops than with simulated yields. Water use efficiency at rainfed crops was naturally higher than at irrigated while it was opposite with water footprint at all three crops.

Session I - Assessment of crop water footprints under present and future climatic conditions (C3015)

Convener: Christian Kersebaum

Alejandro Blas :

Comparison of water footprints of Mediterranean and American diets

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Keywords: Water footprint, Diets, Food production sustainability

Food production sustainability has gained huge importance in recent years, and food consumption trends and patterns are nowadays a key to improve overall sustainability. Therefore, one of the main challenges of this century will be the consumption of healthier and sustainable diets. The issue can only be addressed through a combination of improvements and integration of agricultural production and food consumption, while respecting the carrying capacity of natural ecosystems. This requires considering the entire products lifecycle, from their production to consumption, and that is why, in terms of water management, concepts as water footprint and virtual water provide the opportunity to link the use of water resources to food production and consumption patterns.

The present study analyses the consumption and water pollution linked to each product of a two weeks menu representative of Mediterranean and American (recommended by the USDA) diets. A study and quantification of the blue, green and grey water footprint, have been done for each product included in these diets. The objective is therefore to obtain preliminary results for comparing the two water footprints of the recommended diets and to identify the products that require more water to be produced. The results showed that the Mediterranean diet has lower water footprint than the recommended American one; 5620 litres less of water per person (401 l/person per day less), equivalent to the capacity of 22 conventional bathtubs. In terms of total fresh water consumption, measured as green and blue water footprint, the Mediterranean diet requires 4150 litres more water per person.

But due to the higher grey water footprint of the American diet (more polluting in terms of nitrogen applied in agriculture because of the assimilation by the environment mostly related to the legume production), requiring 9770 litres of water more per person than the Mediterranean diet, the total water footprint is higher in the American one. Results indicated also that Mediterranean summer menu, with season fruits and vegetables, is the one with less water footprint (35.6 m3 / person / week). Also, the green water footprint is the main footprint of both diets, (75% for the Mediterranean and 69% in the case of the American). In terms of products, olive oil is the ingredient that contributes most to the total water footprint in the Mediterranean diet (nearly 21%), while in the American diet corresponds to beef meat (14%).

Session I - Assessment of crop water footprints under present and future climatic conditions (C3015)

Convener: Christian Kersebaum

Ángel de Miguel :

The water footprint of agriculture in Duero river basin

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Keywords: water footprint, nitrogen leaching, crop evapotranspitration, sustainability assesment

The aim of this study is to evaluate the green, blue and grey water footprint (WF) of crops in the Duero river basin. For this purpose a spatial-explicit model, CWUModel, was developed. CWUModel is able to estimate the green and blue water consumed by crops and the water needed to assimilate the nitrogen leaching of fertilizer application. Thanks to the spatial analysis, blue water footprint has also been compared with the monthly water availability in the river basin, identifying the actual and future water stress level in different areas. By incorporating economic criteria in the water footprint assessment, the water and land apparent productivity in agriculture was also estimated. A sensitivity analysis was developed to evaluate the effect of the uncertainty in the sources of information used on the predictions of the model.

The total WF of cereals in the Spanish Duero river basin was simulated in 9,473 Mm3/y (59% green, 19% blue and 21% grey). Cultivation of crops in rainfed lands is responsible of 5,548 Mm3/y of WF (86% green and 14% grey), whereas irrigated WF is established in 3,924 Mm3/y (20% green, 47% blue and 33% grey). Barley is the crop with the higher WF, with almost 37% of total, followed by wheat (17%). Although maize makes up 16% of the total WF of the basin, the blue and grey components reach the 36% of the total blue and grey WF of the basin.

Green water is also essential for irrigated crops such as long-cycle cereals, accounting for more than 45% of their total water consumption. Nonetheless, blue water is a key component in the productivity of agriculture. The sustainability assessment shows that the blue WF of agriculture is responsible for water stress in 2-5 months of the year in the river basin. The presumable expansion of irrigation in the next years could hamper the water management, despite being a relatively humid basin.

Session II - Water footprints, sustainability and virtual water trade, 7th March 2016, 14.00-15.30

Carole Dalin :

Who is eating up the world's aquifers?

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Keywords: food security; agricultural sustainability; groundwater depletion; water footprint; food trade

Water resources, essential to sustain human life, livelihoods and ecosystems, are under increasing pressure from population growth, socio-economic development and global climate change. As the largest freshwater resource on Earth, groundwater is key for human development and food security. Yet, excessive abstraction of groundwater for irrigation, driven by an increasing demand for food in recent decades, is leading to fast exhaustion of groundwater reserves in major agricultural areas of the world. Some of the highest depletion rates are observed in Pakistan, India, California Central Valley and the North China Plain aquifers. In addition, the growing economy and population of several countries, such as India and China, makes prospects of future available water and food worrisome. In this context, it is becoming particularly challenging to sustainably feed the world population, without exhausting our water resources.

Besides, food production and consumption across the globe have become increasingly interconnected, with many areas' agricultural production destined to remote consumers. In this globalisation era, trade is crucial to the world's food system. As a transfer of water-intensive goods, across regions with varying levels of water productivity, food trade can save significant volumes of water resources globally.

This situation makes it essential to address the issue of groundwater overuse for global food supply, accounting for international food trade. To do so, we quantify the current use of non-renewable groundwater for all major crops, in all countries of the world, accounting for various water productivity and for trade flows. This will highlight areas requiring quickest attention, exposing major exporters and importers of non-renewable groundwater, and thus help explore solutions to improve the sustainability of global food supply.

Pirjo Peltonen-Sainio :

Water-smart-agriculture to cope with changing climate at high latitudes

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Keywords: Rainfed production, precipitation, climate change, water management systems

Finland has exceptional, good-quality freshwater resources. However, Finnish agriculture is rainfed though water deficit is common in these high latitude temperate regions with high between season and within season spatial and temporal variations in water availability. Only 3% of arable land is currently irrigated, almost exclusively for horticultural production. Climate change could, however, increase the frequency of episodes with drought and elevated temperature in the future and initiate a call for development of irrigation systems.

On the other hand, not only irrigation systems as such, but more comprehensive year round water management systems in crop production are likely needed as both autumn and winter time precipitation are projected to increase substantially. Potential to improve the adaptive capacity of agriculture to cope with the harmful impacts of climate change in the future does not only originate from Finland being in general a water-rich country. Even one third of our fields are located next to the shorelines of inland waterways, which is a national-cultural heritage that prehistoric ancestors provided when they settled the current regions of Finland and organized agrarian societies close to waterways.

However, the development of agricultural water management systems will differ depending on region and further steps to be taken along with technological developments call for thorough considerations of water sufficiency and availability for large-scale irrigation needed for a relatively short time period. Also socio-economic obstacles, like farmers' inexperience in irrigation in field crop production and the diffuse farm structure, and thereby the potential reluctance to invest, needs to be taken into consideration. To support long-term decision-making processes as well as adaptation to climate change calls for comprehensive strategies of water-smart-agriculture that also considers virtual water trade to Finland from increasingly water scarce countries.

Bosko Blagojevic :

Cooperative allocation of blue water footprint benefits

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Keywords: water allocation, river basin models, cooperative game theory

Surface reservoirs serve as major controllers of water storage, distribution and water allocation within multipurpose water resources systems. In water scarcity environment, main problem is how to share water among users. There are two general approaches to water allocation management. One is the top-down approach, where water management planers have domination. The other is the bottom-up approach, with active participation of interested stakeholders.

In top-down approach water management planers commonly use computerized river basin models such as MODSIM, HEC-ResSIM, or WEAP to maximize benefits derived by proper operation of water resources system located in given river basin or connected basins. By using any of these models the utility of the system (expectedly) can be maximized. However, in their optimization parts (mostly standard LP) models are generally 'blind', in a sense that they cannot recognize to whom to deliver water if two or more users share the same priority and/or their demands are significantly different in both time and space instances. Also, an issue of defining priorities in water allocation is a challenge for the planners because it is hard to implement water allocation plan if involved water users (stakeholders) do not regard it as being fair. This is especially true if model output shows that one or more stakeholders do not get any water in favour of benefit achieved for the entire system. On the other hand, water allocation simulated with the same model, but merely based on bottom-up approach, usually do not generate output which indicates efficient use of water for the whole system, simply because each stakeholder intends to maximize only his own benefit.

In this paper we present an illustrative example which describes a framework for fair and efficient allocation of incremental benefits within multiple purposes system with surface reservoirs. Our approach is based on the cooperative game theory (CGT) and is aimed at determining fair and efficient utility share of the beneficiaries within the system. CGT solution method considers the gains of each stakeholder which corresponds to respecting the bottom-up approach, and indicates gains obtained through the water planner’s solution, which corresponds to the top-down approach. By using such analysis framework benefit of the whole system will be at maximum (the same as obtained by the optimization model), but allocation of benefits will be fair and stakeholders will be motivated to cooperate.

Bosko Blagojevic :

Defining land suitability for irrigation based on water use efficiency: A case study from Vojvodina Province (Servia)

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Keywords: water use efficiency in irrigation, GIS, AHP

Irrigation in Europe is developing continuously, including within many countries that only recently became members of the EU, a trend that will probably continue. Serbia is a candidate country with a predominantly agriculture-based economy. Its Northern Province of Vojvodina is the main agricultural region, 75% of which is arable land; however, out of the total province area (21,506 km2) only 3% is irrigated.

This paper presents a spatially-based multi-criteria evaluation of land suitability for irrigation in the Vojvodina Province, Serbia based on water use efficiency (due to future climate changes). In first step all area within first two classes of soil suitability for irrigation (Class 5 - no limitation for sustained use under irrigation and Class 4 - slight soil limitation for sustained use under irrigation) are extracted in GIS environment. After that, in step two, four criteria related to water use efficiency were selected to define suitability (priority) of the land for irrigation development: the total available water in the root zone, water deficit, drought and distance from water bodies. Since criteria for land suitability for irrigation are of heterogeneous types (qualitative and/or quantitative), different forms (continuous or discrete) and different domains of measurement, it is crucial to standardize all sub-criteria by bringing them into a common domain of measurement.

Therefore, to each cell in the four criteria layers is assigned a different ratings (values) on a scale from 1 (low priority for irrigation) to 5 (very high priority) according to experts' experience and domestic and international references. Weights of spatial criteria and sub-criteria were derived in third step with the Analytic hierarchy process (AHP) by group of experts in the subject area. Aggregation of weighted criteria into the final irrigation suitability map is performed in the GIS environment, by multiplying the cell values in each of the criterion layers by the corresponding final weight of the criterion. The final result is map which represents spatial priorities in irrigation development, when goal is to optimize water use efficiency.

Session III - Remote sensing of Agricultural Water Footprint, 7th March 2016, 14.00-15.30

Marios Spiliotopoulos :

The use of earth observation methods for estimating regional crop evapotranspiration and yield for water footprint accounting

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Remote Sensing techniques have become the trend in estimating actual crop evapotranspiration and hence crop water requirements, the last decades due to the advantages they offer to users. Low cost, regional data and maps instead of point measurements and of course time saving are included in the advantages. The use of earth observation data supports models' accuracy in the procedure for accounting water footprints (WFP), since no average values are used but instead users have the real values of the specific parameters. The study provides two examples of how remote sensing techniques are used essentially for providing crop evapotranspiration along with crop yield, two basic parameters, for accounting WFP. The methodology proposed refers to the Mediterranean's' region conditions and can be applied after inferring the necessary field data of each crop.

In this study, Surface Energy Balance Algorithm for Land (SEBAL) was adopted, under the essential adaptations for local soil and meteorological conditions for estimating groundnuts water requirements. Landsat-5 TM and 7 ETM+ images were used to retrieve the needed spectral data enhanced with empirical equations regarding crop canopy factors, in order to increase crop evapotranspiration accuracy. Maps of Crop Evapotranspiration (ETc) were created using the SEBAL modified model for the area of interest. The results have been compared to the measurements from an evaporation pan (which was used as a reference). The statistical comparison has shown that the modified SEBAL can predict ETc in a very effective and accurate way and provide WFP modelers with high level crop water data.

Yield prediction plays a vital role in calculating the WFP. Having real values than taking reference (or averaged) values from FAO is an advantage that Earth Observation means can provide. This is very important in econometric or any other predicting models used for estimating WFP because it reduces their accuracy when using average data. In this context, crop and soil parameters along with remotely sensed data can be used. Crop and soil parameters along with NDVI have been correlated to examine if crop yield can be predicted. Statistical and remote sensing techniques were then applied to derive and map a crop yield model. The algorithm developed indicates that remote sensing observations can predict crop yields effectively and accurately. Using the statistical student's T test, it has been found that the predicted values and real values of the crop yield do not have any statistically significant difference.

Oscar Hartogensis :

New development in scintillometry:
Direct measurement of evapotranspiration at field- to regional scales

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Keywords: evapotranspiration,scintillometer,microwave,remote-sensing

Scintillometry has become a generally accepted technique to obtain area-averaged turbulent fluxes at the 0.1 – 10 km scale. Optical scintillometers that yield the sensible heat flux (H) have been tested under a wide range of circumstances and are commercially available. To go to evapotranspiration (ET) estimates, typically an energy balance approach is used. In this contribution we will report on two novel developments to retrieve area-averaged ET more directly with the scintillometer technique.

The first one is on the development of a micro-wave scintillometer (MWS) with which, in combination with an existing large aperture optical scintillometer (LAS), ET can be determined on a scale of 1-10km. To this end our team developed a 160GHz micro-wave scintillometer in cooperation with RPG (Radiometer Physics GmbH, Meckenheim, Germany). Use is made of the fact that scintillations detected at a distance of a radio-wave source are mainly due to water vapour fluctuations, whereas temperature fluctuations are causing primarily scintillations in the optical wavelength region.

The second one is based on a laser scintillometer technique that allows to determine the turbulent H_2O and CO_2 fluxes with a faster statistical convergence than the classical eddy-covariance method. This enables determining turbulent fluxes during strongly non-stationary conditions, e.g. in the intermittent stable boundary layer or rapidly changing cloud-cover. In our new method, we suggest a hybrid setup that combines a point-sensor for scalar H_2O and CO_2 with a dual-beam laser scintillometer (DBLS). With the DBLS installed in homogeneous areas, turbulence is averaged both in time and space, allowing short averaging flux intervals down to a couple of seconds. This allows us to broaden our understanding of the ET process, such as its response to rapid changes in solar radiation.

Piotr Struzik :

Limitation of water availability for crops, monitored by satellite products during 2015 drought in Poland

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Keywords: drought, remote sensing, evapotranspiration, soil moisture

In the year 2015, most part of Central-Eastern Europe suffered catastrophic drought, classified as meteorological, agriculture and hydrological. In the part of Poland, it was a reason of substantial decrease or even complete loss of yield for 14 types of crops. Identified financial losses are above 240 M€. Low flows in the rivers caused problems with ship traffic. Also combined low flow and high temperature of water, was reason of problems for power plants cooling systems.

Both satellite products and indices calculated from ground observations were used for monitoring of affected areas. Satellite products related to the water cycle monitoring operationally used in IMWM service were found as very useful for drought monitoring. The areas affected by drought were identified by soil moisture and actual evapotranspiration products. The Hydrological SAF product concerning Soil Wetness Index (SWI) in four layers of soil, shown very deep drought development, up to 1 m of depth. In the areas affected by very low SWI, significant decrease of actual evapotranspiration determined by Land SAF "evapotranspiration" (ET) product were observed. Very good coincidence between SWI and ET was observed. Also typical vegetation indices like VCI, VHI were analysed.

Ground based observations used for calculation of Climatic Water Balance (CWG) and reference evapotranspiration shown good correlation with processes observed by satellite products. High negative values of CWG and high values of reference ET were found at the same areas as low values of SWI and actual ET. Also thermal conditions of this year were unusual. Calculated length of thermal summer season in 2015 was much longer than 30 years average.

Common use of remote sensing products and indices retrieved from ground measurement for deep drought monitoring was presented.

Session I - Assessment of crop water footprints under present and future climatic conditions, 7th March 2016, 16.00-17.30

Domenico Ventrella :

Green and blue water footprint of winter wheat cultivation at regional scale in two European case-studies

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Keywords: green water, blue water, winter wheat, irrigation requirement

In this study a simulation model analysis at regional scale was carried out in order to evaluate the impact of climate change on water use of winter wheat cultivated in two areas of Germany and Italy with particular reference to the consumptive use of green (GW) and blue water (BW) and their relative water footprint.
The study is focused on two areas strategically important for agriculture: Märkisch Oderland in Germany and district of Foggia in southern Italy. The spatial variability was taken into account considering different climatic cells for each case study and several soils.

DSSAT v.4.5 and Hermes models were applied in continuous runs (as monoculture) with unique initialization for each combination of climate and soil regarding soil water content, Nitrogen and organic Carbon content. For both the locations the typical agronomical management was considered. Annual yield (t ha-1), biomass (t ha-1), green and blue water (mm), irrigation, drainage (mm) and N leaching (kg ha-1) were the main output variables considered in this study.
According to Siebert and Doll (2010), the consumptive use of green water and blue water was obtained from the soil/plant water balance as simulated by DSSAT and Hermes in two steps considering two cropping systems based on winter wheat cultivated in rainfed and irrigated regimes. The irrigation was simulated restoring the soil water content at field capacity when the crop available soil water was depleted for 50% and 80% for Märkisch Oderland and Foggia Distric, respectively. In such way we could simulate a systematic irrigation for the German case-study and a supplemental irrigation for Italian case-study, mainly concentrated in April and May.
The water footprint related to rainfed and irrigated winter wheat was expressed in terms of t m-3 of grain dry matter yield simulated in rainfed and irrigated condition.
The green water component was predominant compared to BW, covering almost 90% of the crop evapotranspiration of winter wheat above all for the Italian case-study.

Green water appeared dependent on the spatial and temporal distribution of rainfall during the crop cycle, but also to the soil characteristics. In particular, results showed that the variability due to the soil, compared to that regarding the climate, had higher impact on wheat yield. However, the climate variability impacted significantly the water footprint related to green water.

Session I - Assessment Of Crop Water Footprints Under Present And Future Climatic Conditions (C3015)

Convener: Joop Kroes

Rick Hogeboom :

Modelling water footprints of crop production on an annual basis using AquaCrop: the case of wheat in China

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Keywords: water footprint, crop water productivity, wheat, inter-annual variability, modelling

A growing world population, socio-economic developments and climate change are likely to increase water scarcity. The need to accurately quantify spatiotemporal patterns of freshwater consumption is therefore paramount – especially in the agricultural sector, the largest water consumer.

The purpose of the current study is to explore the potential of using FAO's crop growth model AquaCrop to simulate the daily soil water balance in both rain-fed and irrigated crop fields over a multi-year period at a high spatial resolution, and to estimate yields and water footprints of crop production on an annual basis. We do this in a case study for wheat in China. We developed a computational framework to automate grid-based runs and make use of datasets with global coverage, given the intention to apply the approach for other crops as well and at the global scale.

We used AquaCrop to generate estimates of evapotranspiration and yield for both spring and winter wheat varieties in China at a 5 x 5 arc minute resolution per year for the period 1980-2010. We gathered and pre-processed grid-based data on climate (daily precipitation, reference evapotranspiration, minimum and maximum temperatures), wheat (spring or winter variety, crop parameters, annual harvested areas, and planting and harvesting dates), soil hydraulic properties and irrigation (annual irrigated areas and irrigation type) and field management. During the simulations we tracked daily soil water balance fluxes over the growing season, allowing us to split crop water use into its green and blue components. Grid-based yields were aggregated to the national level and scaled to match country-average annual yields as reported in FAOSTAT. Water footprints were calculated by dividing evapotranspiration over the growing season by the season yield.

Resulting water footprint and yield estimates at this high spatiotemporal resolution allow us to analyse spatiotemporal patterns, variations and trends governed by varying climatic conditions and changes in irrigated and harvested areas. Furthermore, these patterns provide a reference for studying the effects of alternative irrigation and land management options (e.g. drip irrigation and mulching) on the water footprint of wheat.

Session I - Assessment Of Crop Water Footprints Under Present And Future Climatic Conditions (C3015)

Convener: Joop Kroes

Muhammad Anjum Iqbal :

Assessment of green water footprints for winter wheat production under present climatic conditions

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Keywords: Green water foot prints , present climatic conditions, winter wheat

Water footprints (WF) provide a modern approach for monitoring the available and future water resources in agricultural production system for food security. In this study green water footprints (GWF) were estimated for winter wheat in the most productive climatic zones of Germany. Wheat zones were divided into two climatic zone i.e. climatic zone I and climatic zone II. This classification is based on climatic conditions, production area and soil types. Each zone has many soils and wheat cultivation areas. Climatic condition was considered from 1990-2011(past 22years).

In these zones wheat production mainly depend upon green water (rainfed). CERES-Wheat model was used to calculate crop yield and water consumption. For this purpose model was calibrated for phenology for both climate zones according to the procedure described by yield gap atlas. According to our simulation, average values for GWF for climate zone I and II were 446.6 and 479.8 m3 /tons, respectively. Highest values for GWF were obtained for climate zone II (5284.3 m3 /tons) as compared to climate zone I (1550.6 m3 /tons). This could be the reasons of bad soil conditions (low field capacity), climatic droughts.

Therefore caused a drastically yield reduction and less water utilization and more drainage loses. According to our results WF of agricultural production system depend upon effective management strategies and minimizing the risk of agricultural crop production.

Session I - Assessment Of Crop Water Footprints Under Present And Future Climatic Conditions (C3015)

Convener: Joop Kroes

Nazli Koseoglu :

The water footprint of the Scotch malt whisky industry

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Keywords: water footprint analysis in beverage industry, water use in Scotch whisky production, consumptive water use

Scotch whisky is the most valuable export of Scotland after oil and gas. Scotch whisky production requires large volumes of high quality water and its raw materials are limited to water, yeast and malting barley as set out in its Protected Geographical Indication description. Its economic and cultural significance as well as its dependency on local resources as a water intensive product makes whisky an interesting case study. As a straightforward indicator of human appropriation of freshwater resources for consumption or production processes, water footprinting can help establish water reduction targets and provide information on water use and environmental performance at the company or industry level in the whisky industry. Water footprint benchmarks established at different levels can help improve water use performance by incentivising adaptation of new technologies to increase water productivity in production and efficiency in wastewater treatment.

In this study we estimated the water footprint (WF) of Scotch whisky industry in Scotland using bottom-up Water Footprint Network methodology. This estimation includes green, blue and grey water used throughout the supply chain considering the production of spring barley and other material inputs (glass bottles and paperboard for packaging) and the operational and process steps of single malt whisky. However, not all material inputs and ingredients were considered due to lack of reliable data. The results of the indirect WF analysis differs slightly depending on adjusted evapotranspiration, crop water use and regional crop yield differences between regions where green WF of spring barley is sourced for whisky production.

The overall indirect and direct components of WF at national scale, respectively, are 612 and 23 million m3/year. The largest contribution to the indirect WF in the whisky supply chain, at 72%, comes from the green water component in spring barley production. On the other hand, grey water for effluent assimilation makes the greatest contribution, at 53%, to the direct WF of production processes. Concentration of pollutants, technology for effluent treatment, fertiliser and other agrichemical application rates in spring barley production as well as the soil parameters and characteristics are compiled from data bases and literature. The results highlight the strong reliance of the Scotch malt whisky industry on quality and availability of local freshwater resource. However local, site and distillery specific information is required to further improve analysis and to provide more representative results.

Session II - Water Footprints, Sustainability and Virtual Water Trade, , 7th March 2016, 16.00-17.30

Petra Hellegers :

The need for a global perspective to address increasing demands for water and food

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Keywords: scales , global perspective, responsible, political and social dimensions

Local water resources worldwide are increasingly influenced by global forces, including changes in climate and water use. International trade in food crops affects local water resources worldwide. Consumers of water-intensive products do not take into account the potentially negative effect of their consumption on water resources elsewhere. Moreover, it is unclear who is responsible and at which scale. In general it remains unclear how to effectively cope with water scarcity at different spatial levels. There are multiple reasons to carefully evaluate the potential of local and system level response-options. In recent decades water productivities have improved substantially, mainly due to agronomic improvements. Today, water productivity is already high in the most productive regions. No large additional gains are foreseen. Also gains in yield per unit of land do not necessarily coincide with water productivity gains, as farmers usually maximise returns on land rather than on water. More importantly, enabling conditions for farmers and water managers to enhance water productivity are not in place. At basin level, conflicts over water (re)allocation hinder cooperation on food production. Subsidies, foreign exchange shortages, reluctance to rely on foreign supplies, and presence of other powerful domestic forces all explain why international trade is often not steered by water scarcity. Besides fluctuating prices of food staples trigger countries to review their food policy in favour of increased self-sufficiency. Such considerations add political and social dimensions to the narrow economic rationale of food trade (which is in favour of specialisation in export crops with a high economic return in water-scarce regions). Other factors that affect the priority of national policies to specialize in high value crops are the level of integration of countries in the global economy, access to markets through trade agreements and confidence in the global market for access to staple food. This means that factors outside of the water domain play an important role. Worldwide there is currently also still an underutilized vast forgotten potential of rainfed agriculture. Many of these areas in Africa, such as upstream areas of the Nile Basin have, however, been destabilized by recent war and civil unrest. Stabilizing them and strengthening intra-basin cooperation via food trade seem to be better strategies than water reallocation. So a global perspective is required that also focuses on factors outside the water domain. This implies that the scope of water resources management needs to be broadened.

Jeroen Vos :

From universal to contextualized water footprint conceptualizations

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Keywords: local values, economic opportunity costs, social distributive effects, environment, social productivity of water use

Water footprint and virtual water conceptualizations depart from a universalized ontology, epistemology and methodology. This conceptualization presumes that for example one cubic meter of virtual water used in the desert coast of Peru to produce asparagus for export can be compared with one cubic meter of virtual water used to produce subsistence food in Bangladesh. In doing so a universal objectivity and neutrality in the valuation of water resources use is sought and portrayed. However, the value of water and its use is extremely variegated across different contexts, scales, interests and actors. We identify four locality-specific valuations that are not taken into account in current conceptualization of virtual water and water footprints. These are: (1) the economic opportunity costs for the use of water; (2) the social distributive effects of the use of water: "who gains and who loses with the use of water"; (3) the environmental effects of the use of water, which goes beyond the calculation of "grey virtual water", and should include fossil energy use; and (4) the local water use rationality of farming system, which is not understood when analysing one sole product from these often complex systems. Not taking into account these locality specific valuations leads to flawed policy recommendations such as a drive to reduce decontextualized water footprints, optimize global virtual water trade, and introduce increasingly strict water stewardship and efficiency standards. These policies and production standards exclude smallholders from supplying agro-export chains as they are regarded not to comply with established water stewardship and efficiency standards. At the same time, a blind eye is kept on processes of resource accumulation by producers that can afford to comply to these myopic standards. In view of this we propose to explore new more comprehensive ways of conceptualizing water footprints. These should take into account local valuations of water, the socio-economic distributive effects and the environmental effects of its use. An example of an alternative indicator is the "social productivity of water use" that calculates the income of different social groups derived from the use of one cubic meter of water in a watershed when used by a particular group of users. This indicator could be used to assess the social distributive effects of policy options or infrastructure alternatives. Local stakeholders should be involved in the assessment of this indicator to increase the comprehensiveness of the assessment.

Frank Niele :

Water-related business risk assessment in the oil & gas industry

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Keywords: energy, fuels, water constraints, cost of adaptation, business risk

Quite some water scarcity, water stress, water security and water footprint tools exist already and are further developed by several institutes. However, none of these tools enable the assessment of business risks resulting from exposures to reported water risks, and none is solution-focused.

Generic approaches to operational water accounting and to calculating costs of water management solutions are needed to enable the comparison of water-related business risk on a like-for-like basis for different energy carriers from fossil to renewable fuels – including biofuels – and from thermal to renewable power.

To enable like-for-like comparisons, a water risk profiling approach is suggested in which operational water needs and constraints are systematically evaluated.

Businesses know their current, and project their future needs for water intake and disposal. On the other hand, academic, governmental and non-governmental institutions investigate physical, regulatory and reputational availabilities of water sources and sinks, both today and with a view to the future.

Evidently, mitigation of water risks necessitates good interfacing between water availability assessment tools and water-related business risk assessment tools. This notion prompts a firm call for collaboration between all stakeholders involved.

When it comes to reducing water stress and vulnerabilities to climate change, the cost of adaptation to – potentially emerging – water constraints is seen as key performance indicator. Hence the suggested water risk profiling approach is designed to assess the "cost of adaptation", which renders it inherently solution-focused."

Ayşe Özge Demir :

The importance of the water footprint of animal fibers production in Turkey

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Keywords: Goat coarse hair, mohair, water footprint, wool

Almost 35 million tons of natural fibers including both plant and animal origin are produced at a global level each year. Cotton obtained from plant seed is the most widely produced natural fiber in Turkey (7%) as in the world. During production of this material used in the textile industry requires a large amount of water footprint (WF). The blue WF (84%) of cotton is closely related with various surface and underground water resources. Whereas, the protections of these resources are crucial for future of life and living organisms.

Turkey has significant potential in animal fiber production. These fibers mainly produced in the country are wool, mohair and goat coarse hair. According to Turkish Statistical Institute (TurkStat)'s report, Turkey has been realized 58.403, 5.460 and 280 tons wool, hair and mohair production in 2014, respectively. However, the production of these fibers has decreased significantly over the last decade. Additionally, there is no comprehensive report on the WFs of animal natural fibers for Turkey. Whereas, especially wool and hair production have enormous importance with almost negligible financial burden and WF. From this point, it is clear that knowing the WFs of animal fibers which is in competition with cotton is important. In this study, it has discussed the importance of the publication of the WF reports on animal fibers.

Session III - Remote Sensing of Agricultural Water Footprint, 7th March 2016, 16.00-17.30

Filiberto Altobelli :

Assessment of the long-term variability of green water footprint with EO-based irrigation advisory services dataset

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Keywords:Green Water footprint (WFgreen), crop water requirements, Earth Observation

Globally, crop evapotranspiration has increased with the expansion of agricultural lands and irrigated areas. In particular, two components of crop water use can be defined: green water use (GW) as the crop evapotranspiration steaming from rain infiltrated on soil, and blue water use (BW) as the amount of crop evapotranspiration steaming from irrigation, that is withdrawn from water bodies. The total crop water use is the sum of blue and green water use and corresponds to actual evapotranspiration. Estimation of GW and BW for a determined crop is an important milestone for planning a more sustainable use of water resources in agriculture.

The crop water footprint (WF) is a good indicator of freshwater used to produce a crop; its two components, green (WFgreen) and blue (WFblue), are calculated as the green and blue water use divided by crop yield. This study aims to assess the spatio-temporal variability of WFgreen of maize cultivated in Sannio Alifano consortium, located in Southern Italy (Campania region). During the irrigation season crop water requirement was estimated with the Penman Monteith equation by using meteorological parameters derived from agrometeorological stations, and spatial and temporal variations of vegetation parameters were retrieved from EO data derived from DEIMOS-1 (spatial resolution of 22 m).

This contribution shows how much GW should be provided to the crop to meet evapotranspiration requirement and how its knowledge can be important for planning the use of water at local level; it also underlines to what extent joining data from innovative tools in irrigation can contribute to assess the sustainability of water management in agriculture.

Marios Spiliotopoulos :

Crop coefficients assessment using METRIC model and relationships with Landsat's TM thermal channel under stress conditions in central Ireland

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Keywords: Crop Coefficients, METRIC, Thermal band, Ireland

Actual Evapotranspiration (ETa) is a key component of the hydrologic cycle, thus improving its assessment is critical for improved understanding and application development. This study, in central Ireland used in situ data from selected meteorological stations to calculate daily ETr values for a cloud-free date when Landsat-5 Thematic Mapper (TM+) imagery was available.

These values were then used to estimate ETa using the METRIC model which is a variation of SEBAL. SEBAL model originally developed for Western Egypt, have not been fully tested in such a humid, temperate maritime climate. METRIC is an image-processing model comprised of a large number of computational sub-models that computes ETa and other energy exchanges as a component of energy balance. ETa values were estimated on a pixel-by-pixel basis using both the original equations and with an adapted methodology using ground based Leaf Area Index (LAI) values computed from the vegetation index EVI2.

No significant change has been reported using the new adapted equations. Crop coefficients derived from METRIC (ETrF) were then produced and compared with the thermal channel - Landsat 5 TM. A very good correlation was found and a simple linear model was produced between maps of temperature and ETrF. This relationship was then validated using the stressed condition case of 12th of July, 2006. A new METRIC ETrF map was produced for this reason and was compared with the modelled one. The results indicated that the ETrF values can be very well estimated using a simple linear relationship from the thermal band of Landsat's thematic mapper, especially when stress conditions are prevailing in the region.

Gheorghe Stancalie :

Satellite based vegetation indices and biophysical parameters for the assessment of the water footprint of crops

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Keywords: satellite, vegetation indices, water footprint, crops

Among the problems Europe is facing at the beginning of the third millennium, the reduction of the water resources, their degrading quality and the occurrence of ever more severe and frequent droughts are of critical importance. Drought is the limiting factor affecting the widest surface as regards the crops. In this context, remote sensing techniques play an important role in crop identification, acreage and production estimation, disease and stress detection, and soil and water resources characterization because they provide spatially explicit information and access to remote locations.

Introduced by Hoekstra (2003) and further developed by Hoekstra and Chapagain (2008), the water footprint (WF) concept can be used as an indicator of appropriation of freshwater resources. The three components of water footprint, blue, green and grey, refer to the volumes of respectively, surface and groundwater, rainfall and water required to assimilate pollution, that are used to produce the crop yield. In the last decade the WF concept has been applied to different types of crops in regions with different climatic conditions.

The paper focuses on exploring the potential of using remote sensing techniques and data for WF assessment of agricultural crops. The paper presents the obtained results concerning the use of vegetation indices (Normalized Difference Vegetation Index - NDVI, Normalized Difference Water Index - NDWI, Normalized Difference Drought Index – NDDI) and biophysical parameters (LAI and fAPAR) for WF for crops studies, highlighting their correlation with the main agrometeorological parameters (precipitation and soil moisture). The vegetation indices and the biophysical parameters were derived from high and medium resolution satellite data (Terra/Aqua -MODIS, LANDSAT ETM+ and SPOT Vegetation/PROBA V and Pleiades). The study areas included agricultural regions in Romania and Greece.

The combination of these parameters brings several limitations regarding the discrepancies in temporal and spatial resolution and data availability, which are described and discussed in detail.

The results of this study show the usefulness of satellite data for water footprint assessment and were obtained by the Remote Sensing Working Group in the framework of the ESSEM COST Action ES1106, "Assessment of EUROpean AGRIculture WATer use and trade under climate change" (EURO-AGRIWAT).

Session IV – Grey Water Footprints, 7th March 2016, 16.00-17.30

Hong Yang :

Assessment of global grey water footprint of major food crops

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Keywords: water footprint, water pollution, fertilizer, food security

Agricultural production is one of the major sources of water pollution in the world. This is closely related to the excess application of fertilizers. Leaching of N and P to water bodies has caused serious degradation of water quality in many places. With the persistent increase in the demand for agricultural products, agricultural intensification evident during the past decades will continue in the future. This will lead to further increase in fertilizer application and consequently water pollution.

Grey water footprint is a measure of the intensity of water pollution caused by water use for human activities. This study conducts a global assessment of grey water footprint for major cereal crops, wheat, maize and rice. A crop model, Python-based EPIC (PEPIT), is applied to quantify the leaching of N and P from the fertilizer application in the three crops on a global scale with 0.5 degree spatial resolution. The hotspots of leaching are identified. The results suggest that based on the definition and method of grey water footprint proposed by the World Water Footprint Network, the grey water footprint in many parts of the world has exceeded their total water resources availability.

This indicates the seriousness of water pollution caused by agricultural production. However, the situation may also call for the development of a realistic measurement of grey water footprint which is more pertinent to water resources management. This paper proposes some alternatives in measuring grey water footprint.

Johannes Deelstra :

Agriculture and the grey water footprint; a case study for Norway

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Keywords: environment, grey water, quality, nutrients

Agriculture and food production is a key driver in terms of land and water degradation and, in many cases, the main source of eutrophication and reduced water quality. In Norway, as in many other countries, the importance of agriculture for environmental quality has been recognised and initiatives have been taken to quantify and reduce environmental pressures. Cost efficient measures to control and reduce the environmental impacts of food production require access to adequate data.

In Norway these data are obtained through the Agricultural Environmental Monitoring Programme (JOVA). The programme has been in operation since the beginning of the 90's and is carried out in a number of small catchments at different locations in Norway, representing different agricultural land use types, soils and weather conditions.

One of the main objectives of the programme is the assessment of runoff, nutrient and soil losses, obtained through continuous discharge measurements in combination with volume proportional water sampling. In addition, yearly detailed information is available on weather data, land use, farming practices, fertiliser application and yield.

The data collected through the JOVA programme will be used to present and discuss different assessments in the calculation of the grey water footprint of agriculture.

Abebe Demissie Chukalla :

Effect of fertilizer strategies on the grey water footprint of irrigated crop productions

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Keywords: grey water footprint, soil water nutrient balance, crop growth, APEX

Reducing the grey water footprint is essential given the increasing pollution associated with food production and the limited assimilation capacity of fresh water. Fertilizer application has both an increasing and decreasing effect on the grey water footprint of a crop by increasing water pollution on the one hand (by leaching and runoff of fertilizers to the water system) and increasing crop yield on the other. This research assesses the net effect of these two opposing factors for different fertilizer application strategies.

The soil-water-nutrient balance and plant growth at field scale are simulated with the Agricultural Policy and Environmental eXtender software (APEX). Organic and non-organic fertilizer strategies with different application intensities are evaluated in terms of their impact on nutrient leaching/runoff, crop yield and resultant grey water footprint. A range of cases is considered, including: different crops (potato, tomato and maize); soils (loam, sandy loam, silty clay loam); different hydrologic years (wet, normal, dry year); and different environments (arid, Bologna, Italy, and semi-arid, Badajoz, Spain).

Lutz Breuer :

Determination of grey water footprints for salinity control with a model inter-comparison and GLUE analysis

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Keywords: salinity, leaching, GLUE, water footprint

Salinization strongly influences the crop production in arid and semi-arid agricultural regions whereby the majority of salts stems from saline irrigation water. The salts need to be washed out from the rooting zone by means of additional irrigation water to maintain a healthy soil for crop growth. In the sense of Water Footprint (WF) accounting, we attribute this leaching requirement to the Grey Water Footprint. Common guidelines by the Food and Agriculture Organization (FAO Irrigation and Drainage Paper 29) give values for optimal salinity levels in the rooting zone which should not be exceeded in order to maintain long term soil productivity and high crop yields. Leaching requirement is often estimated by an empirical relationship between root zone salinity and crop salt tolerance whereby recent studies report that a more sophisticated modelling approach is needed. Existing models that simulate the water balance, leaching requirement and salt balance differ substantially in their model structure and parameterization requirement.

Therefore, we compared a set of models and analysed it in the frame of a Global Likelihood and Uncertainty Estimation (GLUE). All selected models differ in complexity as well as their focus on either water balance (Hydrus-1D/UNSACTCHEM), crop growth (Aquacrop, SWAP) or crop growth and nutrient/pesticide movement (RZWQM). The models are tested in a case study with a three years observed dataset for soil water content and salinity concentration for growing maize in southern Portugal in dry sub-humid to semi-arid climate. All models are capable of simulating the observed water balance but underestimate the salinity balance. Evapotranspiration (ET) and the ratios of evaporation (E) to transpiration (T) differ greatly, e.g. SWAP estimates an ET of about 700 mm with an E/T-ratio of 0.17 while RZWQM gives an ET of about 620 mm with an E/T-ratio of 0.33. Models, which predict a lower evaporation tend to depict higher percolation rates. But there is no strong correlation of percolation with transpiration.

All in all, salinity management is crucial, in particular in water scarce regions where irrigation is essential for agriculture production. The methods presented here (model inter-comparison, GLUE) are helpful for grey water footprint assessment regarding salinity but also in general, because the models can also be applied for estimating grey WF of other pollutants (e.g. nitrogen and pesticides) in a sophisticated manner.

Ana M. Tarquis :

Agronomic concepts of grey water footprint. A case study in a fertirrigated melon crop under semiarid conditions

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Keywords: nitrates, mineralization, water quality, irrigation, leaching

This paper reviews the methodologies proposed by several authors to calculate green, blue and grey water footprint, as well as total water footprint. We describe how we have employed these methodologies in a three year field experiment. The latter involves a fertirrigated melon crop under mineral fertilization using eleven different rates ranging from 11 to 393 kg ha-1 N in semiarid conditions where the irrigation is necessary to maintain production. We find that the different methodologies do not consider the scenario where green water footprint is zero and the irrigation water has high salt content.

For example, the scenario 'best management of drip irrigation' requires the application of larger volumes of water to avoid salt accumulation in the soil and consequent loss of yield. We propose modifications to the calculation of water footprint to cover this scenario. In our calculation the blue water footprint includes the extra consumption of irrigation water that the farmer has to apply to compensate the failure of uniformity on discharge of drips, percolation out of control or salts leaching, which depends on the salt tolerance of the crop, soil and quality of irrigation water, to ensure the fruit yield.

With respect to the grey water footprint, the fertilizer rate is not the only N source to be lost. It is necessary to considerer other N sources, like the N content in the irrigation water and in the soil (mineral and mineralized during the crop period). In addition, drainage water and nitrate leaching concentration should be taken into account. The reviewed methodologies underestimated the water footprint in our experiment.

With the new considerations proposed, the treatments with the N optimum dose obtained a total water footprint ranging between 127.8 and 151.7 m3 t-1. Treatments with the lowest N dose had higher values (145.7 and 158.4 m3 t-1), but the highest values were obtained in treatments with an N excess (226.0 and 355.0 m3 t-1).

First Plenary Session 8th March 2016: 9.00-10.30

Martin van Ittersum :

Mapping opportunities for sustainable intensification: the global yield gap and water productivity atlas

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Yield gap analysis has been a well know notion in crop science since the late 1980s, but it has become popular only recently. Yield gaps are defined as the difference between actual farmers' yields and potential yield. Potential yields assume optimal crop growth achieved by competent crop and soil management that avoids yield limitation and reduction from nutrient deficiencies, weeds, pests and diseases. Potential yields are location-specific and depend on crop genetics, solar radiation, temperature and water supply during crop growth and they can be calculated for both rainfed (water-limited potential) and irrigation conditions.

Yield gap analysis is generally regarded a helpful starting point for mapping the opportunities for sustainable intensification of agricultural systems, i.e. *where can we produce how much (more) food on existing cropland*. In the global yield gap atlas project (GYGA – www.yieldgap.org) we aim to map yield gaps of all important food crops in every food producing country. A global protocol has been developed to map the yield gaps in an agronomically robust and reproducible manner. The global protocol is always applied with local data and local experts are involved in the evaluation of modelling and yield gap analysis results. It has now been applied for cereal crops to 25 countries and another ca. 25 countries are on their way, thus creating a unique database.

An important component of sustainable intensification is the (sustainable) use of natural resources, including water and nutrients and environmental impact of agricultural production. Potential and actual water productivity is part of the indicators calculated in the Atlas and expressed in kg per mm water (per ha). Nitrogen and phosphorus use efficiencies are other crucial indicators in the characterization of opportunities for sustainable intensification, and we are planning new projects to add these indicators.

This presentation will focus on three issues: 1. the need of using local data and evaluation in agronomic studies; 2. examples of contrasting yield gaps, water productivities, nutrient use efficiencies and their implications; 3. applications of yield gap analysis in food security assessments.

Huub Rijnaarts :

From virtual water to circular water concepts

Water Nexus STW research program: brackish water as a resource for solving agricultural and industrial fresh water needs

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WATER NEXUS is developing integral solutions for problems with water scarcity in delta areas worldwide. Salt impacted water is considered as a resource, and not as a threat. The economy of deltas becomes increasingly impacted by freshwater scarcity as a result of reduced river discharges, sea level rise and salt water intrusion. This is combined with growing fresh water demands, to a large extend originating from the agro and industrial sectors. WATER NEXUS is a recently started research program with a team of 17 PhD and post doc researchers to develop a coherent set of management and treatment approaches that support large volume water supply systems as needed for agriculture and industry. The approach is based on the following principles:

- complete reuse and recirculation of used water,
- mild desalination and compound specific treatment of natural and used salty water streams,
- storage and treatment of water in green infrastructure, and
- fresh water recharge in shallow (under agricultural land), and deeper (in aquifers) subsurface systems.

Key to WATER NEXUS is that program partners cover the entire innovation chain: i.e. partners are from universities (7), institutes for applied research (4), technology providers & consultants (11), water managers (5) and large agro and industrial end users (4). The Water Nexus research plans will be presented during the conference, and discussed in the context of Water Footprints.

Jay Lund :

Water resources and environmental system engineering -

Agriculture and drought in California with future implications

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In the last two years of drought in California deprived agricultural water users of about one third of their water supplies, yet land fallowing was less than 10% and economic losses were only about 4%. Several layers of adaptation were responsible for this relative success. The major success was the availability of substitute groundwater, with resulting overdraft problems and precipitation of new groundwater regulations. The marketing of remaining water also eased the economic impact of drought as higher-priority water users sold water to growers of higher-valued crops. High global prices for higher-valued agricultural products which employ more people per hectare continued to drive crop shifts. This greatly dampened absolute employment losses in agriculture. Overall, the economic footprint of water use has been more important than its biomass production footprint.

The drought, at this time, is still ongoing as we await the outcome of the current wet season which ends in April. However, the drought has led to several impacts which are likely to be enduring. These include: a) new groundwater legislation which will eventually end major groundwater overdraft in California, increasing water scarcity for agriculture but improving long-term groundwater availability for permanent and higher-valued crops during droughts, b) greater pressure to reduce urban water use in California, and c) better understanding of the need to manage ecosystems over a range of flow and temperature conditions.

Session I - Assessment of crop water footprints under present and future climatic conditions, 8th March 2016, 11.00-12.30

Josef Eitzinger :

Crop water footprints under complex climatological conditions - case study Austria

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Keywords: crop water footprints, climate zones, Austria

Efficient water use in agricultural crop production is one of the most important issues for global food security in the coming decades. Our study in the frame of the COST 1106 action highlights important parameters for Water Footprint estimation of main crops under different climatic regions and its diversivication over the complex topographical and climatological conditions over Austria. Based on a climatological and soil classification for agricultural land in Austria water use efficiency and water footprint were simulated with the calibrated model AQUACROP for several main crops over a period of 30 years.

The results are analysed in respect to spatial variations of crop-soil water balance and crop water use and observed trends over the period. Green water footprint was estimated for rainfed conditions, as the current dominant production condition in Austria, however, blue water footprint was additionally considered as an option for irrigated regions and analysed on its potential trend due to ongoing climate change.

Session I - Assessment of Crop Water footprints under present and Future Climatic Conditions (C3015)

Convener: Marius Heinen

Jüri Kadaja :

Potential green and blue water footprints of potato in Estonian conditions

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Keywords: Estonia, meteorologically possible yield, potato, water footprint

Potato yields and evapotranspiration were calculated by the potato crop model POMOD. The meteorologically possible yield (MPY) was exploited, which is the maximum yield attainable under the existing irradiance and meteorological conditions with optimal soil fertility and agrotechnology. Calculations were carried out for three different climate regions of Estonia: continental (meteorological station Tartu, applicable data series for 111 years), sub-continental (Tallinn, 92 years) and maritime (Kuressaare, 89 years), while biological parameters of early ('Maret') and late ('Anti') varieties were considered. The following model scenarios were simulated: the baseline rain-fed run, irrigation keeping water content at or over 60% of field capacity, drainage keeping water content below field capacity, while all scenarios were applied for both soil hydrological situations: existing and prevented natural outflow (involves deep percolation and runoff).

Mean baseline MPY for potato varies between 42 and 56 t ha^{-1}, potential green water footprint (WF) of rain-fed crop varied from 46 to 129 m^3 ton^{-1}. The WF is lower for the late variety and for Kuressaare where less precipitation caused a decreased evapotranspiration. In continental sites restricted outflow essentially increased WF. In continental Tartu the difference between natural and restricted outflow reached up to 77 m^3 ton^{-1} for late variety. This is due to water-logging, which caused considerable decrease of yield (up to failure) at high evaporation demand in some years, causing very high variability of WF. Irrigation increased both MPY and WF. Drainage increased yield mostly in case of restricted natural outflow in continental sites, at the same time decreasing WF markedly.

Potentially, if the irrigation water amount is exactly as needed by the crop, the blue WF would be 8.5-19.5 m^3 ton^{-1}, being higher for maritime climate an early variety and is 12.7-34.5% of the overall WF. In opposite to absolute values, this percentage is higher for late variety. Restricted outflow decreases and two-way management increases the blue WF percentage. Differences in distributions of blue and green WF between irrigation alone and two-way management appear in the low region of blue and high region of green WF, being considerable in continental and hardly visible in maritime climate. As well as overall WF, its components green and blue WF are influenced by frequent existence of water excess in parallel to water deficit, which is quite common situation in the higher latitudes where Estonia is located.

Session I - Assessment of Crop Water footprints under present and Future Climatic Conditions (C3015)

Convener: Marius Heinen

Laura Miguel Ayala :

Impact of soybean expansion on water footprint in the Amazon under climate change scenarios

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Keywords: Phosphorus, Water Footprint, Soybean production, Deforestation, Climate change

One of the most problematic issues in natural environment is agricultural expansion and intensification. The expansion of soybean fields and the subsequent land use change is remarkably increasing in countries like Brazil in the last decades. The increase in water and nutrient use in relation to soybean production are known as potential sources of contamination and can have negative impacts in the adjacent water bodies. These impacts can be intensified by the projected Climate Change effects in tropical areas.
Several methods can be applied to assess these environmental impacts from different perspectives. These methods are Life Cycle Assessment, Ecological Footprint method and Water Footprint Assessment, among others. The WFA aims at studying the sustainability of water footprint (WF) of processes, products, organisations or within geographic areas from environmental, economic and social dimensions that leads to formulation of water footprint response strategies. WFA proves to be a useful methodology to assess the impact of crop production since it has a strong link between water, pollution and land-use and climate changes.
The aim of this study is to carry out a Water Footprint Assessment to account the water footprint related to the production of soybean in order to understand the sustainability of the WF in the Tapajós River basin, an Amazonian area with large expansion and intensification of soybean. The study applied the WFA methodology and used both locally and globally available data. We identified the environmental hotspots (WF potentially unsustainable areas). The WF and the hotspots were spatially plotted along the river basin with ArcGIS in order to assess the current impact of soybean expansion (baseline). We also calculated potential areas of change in WF 2050 projection by using a land use change scenario (Ssp5 scenario) that includes climate change effects.

This study presents the potential effects of soybean expansion in terms of water use and highlights the most challenging areas in sustainability terms (hotspots) in the future scenario. Our findings indicate that the current soybean production systems are prone to have a significant impact beyond protection limits in the future, especially in relation to water pollution (grey water footprint and water pollution levels) and water use (green water scarcity). Management practices can play an important role to achieve sustainability by the help of, e.g. water consumption regulations to stimulate water use efficiency, reduction of crop water use, and evapotranspiration, and optimal fertilizer application control.

Session I - Assessment of Crop Water footprints under present and Future Climatic Conditions (C3015)

Convener: Marius Heinen

Francesca Natali :

Computing crops water footprint for economic and agronomic sustainability: experiences from Europe and Israel

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Keywords: crop water requirement; water sustainability, indicators

The sustainable management of water resources cannot be kept separated from an afterthought of agricultural development, which is well known coming into play in the use of water. The adoption of the water footprint (WF) demonstrated to be very useful in the communication of the water value, giving direct and easy-to-understand information to both institutional actors and consumers. But yet, there are many aspects that are still little considered, as that of estimating an indicator of sustainability able to integrate economic, environmental and social aspects.

The aim of this study was to investigate environmental and economic aspects related to selected irrigated crops, through the use of WF. Information on the economic and environmental value of water, in fact, can assist decision making process related to the planning and management of agricultural activities.

In particular, two pilot areas were considered: Israel (Arava area) and Italy (Campania Region), with different climates, agricultural, environment and economic systems. A database of daily meteorological data was created from weather local stations. In Italy 15 weather stations managed by Agrometeorological Service of Campania Region have been considered; In Israel the dataset came from Southern Arava Center meteorological station. For both areas, reference evapotranspiration was estimated using the FAO Software Et0 calculator.

In each country three irrigated crops were considered: silage maize, tomato and tobacco In Italy; and date, potato and tomato in Israel. The crop growth periods and the different crop coefficients (Kc) were considered and daily crop evapotranspiration was then calculated.

Based on collected data, beside crop WF, other two indicators were defined and estimated: WF of the gross margin, and of WF of job. The first describes the economic efficiency of irrigation in terms of water footprint, while the second shows the importance of an efficient use of water for irrigation through labour costs.

The proposed methodology, based on the water footprint, allowed to assess and compare different agricultural productions and farming systems in terms of environmental, economic and social outcomes for a given volume of water

Session II -Water footprints, sustainability and Virtual Water Trade, 8th March 2016, 11.00-12.30

Davy Vanham :

Does the water footprint concept provide relevant information to address the water-food-energy-ecosystem nexus?

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Keywords: nexus, water-food-energy, water-food-energy-ecosystem, water nexus, water footprint

This paper is a perspective paper, which investigates whether the water footprint (WF) concept addresses the water-food-energy-ecosystem nexus. First, the nexus links between (1) the planetary boundary freshwater resources (green and blue water resources) and (2) food security, energy security, blue water supply security and water for environmental flows/water for other ecosystem services (ES) are analysed and graphically presented. Second, the WF concept is concisely discussed. Third, with respect to the nexus, global water resources (green and blue) availability and use are discussed and graphically presented with an indication of quantities obtained from the literature.

It is shown which of these water uses are represented in WF accounting. This evaluation shows that general water management and WF studies only account for the water uses agriculture, industry and domestic water. Important water uses are however generally not identified as separate entities or even included, i.e. green and blue water resources for aquaculture, wild foods, biofuels, hydroelectric cooling, hydropower, recreation/tourism, forestry (for energy and other biomass uses) and navigation. Fourth, therefore a list of essential separate components to be included within WF accounting is presented. The latter would be more coherent with the water-food-energy-ecosystem nexus and provide valuable extra information and statistics.

Eleanor Murphy :

Water footprinting of milk production systems in Ireland

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Keywords: grass, grazing, feed, dairy sustainability, LCA

Finite freshwater availability could become a limiting factor for the global growth of the agri-food sector. Quantifying the water footprint of agricultural outputs and identifying hot spots of water consumption is an important first step in identifying and reducing the pressures on freshwater resources resulting from agricultural production systems. The objective of this study was to determine the primary contributors to freshwater consumption, expressed as a water footprint (WF), and associated environmental impacts for the production of one kg of fat-and-protein corrected milk (FPCM), on 24 Irish dairy farms.

The footprint comprises of the consumption of soil moisture due to evapotranspiration (green water), and the consumption of ground and surface water (blue water), and includes freshwater used for cultivation of crops for concentrate production, on-farm cultivation of grass or fodder and water required for animal husbandry and farm maintenance. The related impact of freshwater consumption on global water stress from producing milk in Ireland was computed based on the water stress index. On the 24 farms evaluated, the production of milk required on average 690 L water/kg FPCM, ranging from 534 L/kg FPCM to 1,107 L/kg FPCM.

The average stress weighted water footprint impact was 0.4 L/kg FPCM across the farms, implying that each liter of milk produced potentially contributed to fresh water scarcity equivalent to the consumption of 0.4 L of freshwater by an average world citizen. Water required for pasture production contributed 85% to the WF, while the water required for grass growth utilised on average 38% of the available rainfall occurring on the farms. Our results show that green water inputs dominate over blue water inputs, irrespective of farm. The utilisation of green water, a plentiful resource, available at a low opportunity cost to produce milk demonstrates the sustainability of milk production in Ireland with respect to water usage. Future studies will be to formulate a model to examine the uncertainty of the input data to deal with limitations regarding data availability and identify the minimum data requirements to calculate an accurate water footprint. As Ireland is limited in land use options due to climate and soil type, we also aim to assess water use efficiencies for milk production systems in Ireland by including competition for land and land use type.

Ayşe Özge Demir :

An evaluation on water footprint of small ruminants in Turkey

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Keywords: Goat, sheep, water footprint

With 1.519 m^3 water amount per capita is considered that Turkey is to be a country with a water shortage. With increasing population and a booming economy and growing cities, the country is progressing in the way of being out of water.

The agricultural sector is the largest consumer of fresh water. The total water footprint (WF) of Turkey is 140 billion m^3/year. Agricultural sector contributes 89%. The water footprint of agriculture is related to the crop production (92%) and grazing (8%).

Sheep and goat constitute 75% and 25%, respectively, of the approximately 41.5 million small ruminant populations in Turkey. As indicated in the WF statistics, according to the weighted average of production systems for the period of 1996-2005 Turkey's live sheep and goat green WF was 3750 and 1943 m3/tonne, 196 and 118 m3/tonne blue WF, and 47 and 1 m3/tonne gray WF, respectively. In terms of products, the total WF of sheep and lamb carcasses and parts are higher than those goats while the WF of goat skins is higher than the sheep skins. Green WF which is the largest component of the WF of small ruminants and its products demonstrates that the production depends on climatic conditions. This situation is a result of extensive based on grazing and semi-intensive production systems based on pasture plus concentrate feed. The blue WF which is the second major component shows the importance of irrigation practices, and so the sustainability of existing water resources. The cause of larger the gray WF in sheep than goats is more industrial production in sheep breeding. With the transition from extensive to intensive production, blue and gray WFs are increasing while green WF is decreasing. Many countries are reducing their WFs by virtual water transfer.

In Turkey, sheep and goat breeding is in a position that cannot be ignored with economic, ecological and sociological aspects. Small ruminants are an insurance of agriculture in rural areas, and especially goats are an important source of animal protein for poor families. Therefore the WFs of small ruminants should be decreased with integrated water resources management practices before virtual water trade or changing food consumption habits.

Ridha Ibidhi :

Water, land and carbon footprints of lamb and chicken meat raised in Tunisia under different farming systems: A comparative study

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Keywords: water footprint, land footprint, carbon footprint, meat, Tunisia

The way in which we use water and land resources is central to the challenge of improving food security across the world, particularly in developing countries. The challenge of providing sufficient food for everyone worldwide has never been greater. Meat production relies highly on natural resources and is responsible for high emissions of greenhouse gases. In this study, we use three footprints indictors, water footprint (litre/ kg of carcass), land footprint (m2/ kg of carcass) and carbon footprint (CO2-eq/ kg carcass), to assess natural resource use and emissions underlying lamb and chicken meat produced in Tunisia under different farming systems. We look at the main farming systems used in Tunisia, the industrial system for chicken meat and three different farming systems for lamb meat production (agro-pastoral using cereal crop-residues, agro-pastoral using barley and pastoral system using barley). The results show that chicken meat is least intensive in terms of water use (4746 litre/kg carcass) and land use (7 m2/kg carcass) with low greenhouse gases emission (3 CO2-eq/ kg carcass) compared to the average water, land and carbon footprints of lamb meat, which amount to 15109 litre, 72 m2 and 23 CO2-eq, respectively.

Lamb meat produced under the agro-pastoral system using cereal crop-residues appears to be the production system with smallest footprint if only looking at water use, while the agro-pastoral system using barley is better in terms of both land use and greenhouse gases emission. The results show that the pastoral system using barley has a larger water, land and carbon footprint than the agro-pastoral system using barley.

Session III - Solutions to improve Water Footprints, 8th March 2016, 11.00-12.30

Pieter van Oel :

How to use proposed water footprint and water productivity benchmarks for crop production?

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Keywords: benchmarks, water footprint, water productivity, uncertainty

As global demand for food increases, claims on freshwater resources may rise to levels for which new response-mechanisms are required. Trade in agricultural goods offers opportunities to release pressures on the globe's areas that are most affected by water scarcity. A basic requirement for assessing possible pathways for improvement is the estimation of consumptive water use (water productivities and water footprints) for food crops in space and time in important agricultural areas worldwide. Estimates of consumptive water use for specific crops have been proposed for use as benchmarks for informing stakeholders in global water governance. This study discusses the usefulness of such benchmarks. We first discusses which decision-makers could be informed by benchmarks such that improvements are actually achieved. In this respect the required level of spatiotemporal detail in estimating crop yields and consumptive water use of crops is discussed. It not easy to accurately estimate evapotranspiration for crops. It is also difficult to relate estimations for evapotranspiration to corresponding crop yields. It is often unclear to what extent commonly applied approaches for averaging data and modelling assumptions affect uncertainties of estimates of consumptive water use. Secondly, we discuss the need for considering contextual information when comparing consumptive water use of crops. Certain agronomic and physiologic factors are known to affect water footprints and productivities.

It is argued that estimates of consumptive water use would become more useful when they would be accompanied by contextual information, such that an action perspective for decision-makers could also be presented. The points discussed are illustrated by a quantitative comparison of findings from literature on water footprints and productivities of wheat. Following this discussion the paper continues by a brief assessment of the validity of claims made in recent literature. Are the conclusions drawn and recommendations made sufficiently supported by the data used and modelling approaches applied? How are different forms of uncertainty dealt with and what could be improved in this respect? Benchmarks, presented in the form of global maps showing spatial variations of temporal averages of consumptive water use of particular crops at coarse resolutions, do not allow for valid assessments of the variation in performance at water system and field levels. Meaningful analyses of variations in consumptive water uses of crops include information on their contributions to problems and solutions. Thus the detail of analysis should comply with spatiotemporal variation of both water uses and related problems.

Mats Lannerstad :

A new approach to consistently assess and compare water use across the global food system

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Keywords: global food system, consumptive water use, livestock, crops, suitability

The global food system is the largest anthropogenic water user. Rising food demands, including a diet shift towards often assumed water intensive livestock products, and a changed climate environment, with projected lower water availability and reduced crop land usability, makes it imperative to identify inefficient water uses throughout the entire food system.

Water pollution and water quality issues can locally be a severe problem impacting food production. However, this study entirely focuses on the mammoth water quantities required during biomass growth on agricultural lands. From a food security perspective it is this consumptive water use demand that poses the major challenge, and that will require wise guidance how to best allocate the limited water resources quantities available for food production, including both green and blue water resources.

Over the last couple of years, the Water Footprint approach from Twente University appears to have become the lingua franca to inform both producers and consumers about impacts on water resources. However, this approach is often criticized for not giving useful guidance to improve water use. It is considered confusing both with regard to water, by merging both water quantity and quality, and with regard to the units of produce that are used for comparison, by often using non-comparable units, like a liter of wine or milk, a kilo of almonds, or a kilo of meat.

The study presented here builds on a combination of different data sets and analyses using a mechanistic livestock model linked and a dynamic vegetation model. The outcome is a new dataset that consistently present comparable consumptive water use estimates for both plant and livestock production from all agricultural lands, i.e. water appropriated on both cultivated and grazed areas. It takes three dimensions into account: the basic difference between plant foods and animal source foods, including feed conversion dynamics; the difference in seasonal and annual appropriation of water resources; and the local suitability of using water for crops. And it uses comparable units, as proteins or calories.

Overall, our analysis shows that after taking into account these different variables, there are situations in which livestock production can be very resource efficient, and often the disparity between livestock and crops narrows significantly. The approach offers a way to better identify hotspots of inefficient and excessive water use in crop and livestock production; a first step towards generating workable water-smart interventions for the entire food system.

Ylva Ran :

Producing food for humans – from crops or animals? Tackling competition for freshwater use between crop and animal production

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Keywords: consumptive water use, livestock production, sustainable intensification, feed-food competition

Freshwater scarcity is a growing global concern, particularly for agriculture, the largest global water user. By 2050, global food production is expected to roughly double. A considerable part of the increase will be through livestock production that, already today, uses almost half of global agricultural freshwater for production of animal feed. In order to meet the sustainable development goals of freshwater availability, and to evaluate the contribution of livestock to global food security, water use assessments should account for the competition for freshwater resources between food and feed crops.

The aim of this study is to develop a new method that can identify environmental impacts associated with consumptive water use (CWU) for livestock, while accounting for food-feed competition. We use a hydrological model, LPJmL, to compute crop and grass water requirements and consult FAO's land suitability index to identify suitability of land for crop production.

To illustrate competition over water resources, we use a water use ratio (WUR), which is the ratio between the maximum amount of human digestible protein (HDP) that could have been produced by food crops, over the amount of HDP produced by livestock, using the same amount of water. The method is conceptualized with a case study of three beef production systems in Uruguay: the first system is based on natural pasture (NP-NP) unsuitable for crop production, the second system is based on seeded pasture (SP-SP) suitable for crop production, and the third is based on seeded pasture combined with a feedlot system (FL-SP).

Results show that the NP-NP system has the largest CWU, 28 000 l/kg beef compared to 14 000 l/kg for the SP-FL and 13 500 l/kg for the SP-SP system. The NP-NP system, however, had a WUR of zero, compared to 1.85 and 1.89 for SP-SP and SP-FL, implying that only the NP-NP system produces more HDP per litre of water than crops (i.e., WUR < 1).

This study shows that livestock systems that value land with low opportunity costs for arable production, e.g. natural pasture, contribute to sustainable use of freshwater resources and have an important role in future food supply. Small changes in feed composition may change the resource competition significantly which can be of great local importance and contribute to more sustainable resource use.

Sebastian Multsch :

Optimisation of desalinated seawater use in irrigation agriculture by a coupled crop water-economic modelling approach

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Keywords: Desalination, Optimization, Simplex-algorithm, Irrigation, Saudi Arabia

Many regions world-wide face serious water scarcity and alternative ways to supply water for irrigation are needed, e.g. in the Middle East and North Africa (MENA) region. Growing crops with desalinated seawater is a promising option to partly satisfy future water demand for agricultural commodities. How to use this rather expensive resource best? The focus of our research is on a spatially explicit, optimal planning of cropping patterns in relation to the water supply by a desalination plant. For this, a software decision support system has been implemented which consists of a graphical user interface (GUI), an optimization algorithm and a database. The latter one holds pre-calculated values of the crop water balance, information on producer prices and the geographic delineation of the study area.

The crop water balance is pre-calculated for each spatial entity and crop with an approach similar to the FAO56 guidelines for computing crop water requirements. Using the well-known simplex optimization algorithm is applied to find cropping pattern which maximize gross margin and water utilization of crop production in relation to water supply as well as other boundary conditions such as irrigation technique, water salinity and desalination cost. We present a case study of a desalination plant, which is currently planned at the coastline of the Arabian Gulf close to Al-Khafjy (Saudi Arabia) with a production capacity of 60,000 m^3/day. We analyse a set of scenarios according to different objective functions (maximize gross margin, maximize water use) and changing boundary conditions (desalination cost, water quality, irrigation technology) which result in various cropping pattern.

This software is not only of interest to optimize and use the full capacity of desalination plants in supplying irrigation water. Furthermore, stakeholders in other regions with limited water available are able to plan as well as improve the water footprint under economic business conditions (e.g. reservoir management) or a given regulatory framework (e.g. transnational water use).

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Session I - Assessment Of Crop Water Footprints Under Present and Future Climatic Conditions, 8th March 2016, 13.30-15.00

Christo Tsadilas :

Industrial tomato cultivation water footprint in pinios river basin. Soil properties interactions

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Keywords: Blue Green Water footprint, Pinios River Basin Greece, Industrial tomato cultivation

The Pinios river basin in central Greece is the most important agricultural production area in Greece with fertile soils but water shortage during summer. These conditions inversely affect both the natural vegetation and the agriculture of the region resulting in irrigation cut backs, over-exploitation of groundwater and significant losses of crop yields. One of the most important agricultural crops cultivated in the region is industrial tomato covering an area of about 5.000 ha resulting in a significant income to the producers.

In the present work, the water footprint (WF) for the planting to harvest period for industrial tomato cultivation was estimated for three consecutive years at 24 different farms in the Pinios River basin. The farms were selected according to the main agro climatic cultivation zones in the catchment, and included the main soil texture classes used for tomato cultivation in central Greece. Green and blue WF estimations were based on datasets obtained by experimental plots for each farm that included volumes of irrigation water, meteorological, soil, and yield performance data.

The WF of 1ton of tomatoes produced in central Greece ranged from 23.4 to 73.4 m3 water. The WF of fresh tomato cultivation varies in the different farms mainly depending on the local agro-climatic character, total tomato production volumes and soil conditions. The green WF component ranged from 1.84 m3/ton to 29.95 m3/ton, or 7.86% to 40.78%of total water footprint, and the blue component ranged from 19.21 m3/ton to 43.50 m3/ton or 23.86% to 73.45% of total water footprint. Significant correlations of WF with soil properties were investigated, identifying soil clay content as an important soil property that regulates WF values. The significant variability of WF values highlights the importance of considering water issues at the local scale. The results of the study revealed the instrumental role of WF that could help in understanding how cultivation of industrial tomato is related to water scarcity and pollution and reveal impacts and actions for the sustainable use of freshwater.

Roel Helmes :

Life cycle water demands of four horticultural crops in the context of zeolite based pesticide application

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Keywords: water, lca, grape, apple, zeolite

The Framework Program 7 research project 'Developing a pool of novel and eco-efficient applications of zeolite for the agriculture sector' (ECOZEO), zeolite based formulations were piloted as a pesticide for four crops: apple, grapes, tomatoes and oranges. A water-focused Life Cycle Assessment was part of the sustainability assessment, investigating how the use of the novel pesticide formulations changes total water demand of the product's life cycle.

An extensive literature review in LCA and water footprint literature was conducted to compare Water Use LCA and Water Footprinting, in the context of these four crops, and to identify the main factors influencing irrigation water use in these crops. The life cycle water demand was calculated for grapes and apples, comparing a zeolite based formulation with conventional fungicide formulations. This analysis focused on irrigation and the fungicide application.

The review of water usages in the four crops provided the key variables that affect water usage: climate, growing medium or soil type, protection type and cultivar. It was concluded that in specific cases the water footprint data and life cycle water demand are equivalent, and that water demands vary broadly across different cultivation conditions. The results from our calculations support that water use for irrigation dominates the life cycle water demand.

Field measurements are highly relevant to calculate life cycle water demand accurately. Local conditions determine the life cycle water demand so strongly that assessments should be based on local data such as field measurements. We also recommend that improvements in life cycle water demand focus on improving irrigation rather than on the production and formulation of the pesticide. Internal benchmarking is more relevant to stimulate farm improvements in irrigation than benchmarking between farms. Also, it is considered important that scope, system boundaries, impact indicators and a guide to the interpretation of the results are clearly specified.

Session I - Assessment Of Crop Water Footprints Under Present and Future Climatic Conditions (C3015)

Convener: Josef Eitzinger

Anna Dalla Marta :

Assessment of water footprint of urban agriculture in Rome, Italy

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Keywords: urban water footprint; crop water requirement; urban agriculture; community garden

The strategies to cope with future climate change scenarios need to take into account the water use at local level, especially in urban areas where water demand and water conflicts among different users may be relevant.

In recent years, urban agriculture is emerging as new competitor among the users of water available in many metropolitan areas, due to the rapid growth of this phenomenon. In this new context, local water management in urban areas must be carefully reconsidered and improvement of tools and approaches is required for a better management of local water resources. Evaluating the water footprint at urban level can be an option to achieve the mentioned goals.

In this study we estimated the water footprint of the most common crops cultivated in the community gardens located in the city of Rome (Italy). To this aim, a specific agro meteorological dataset was created by using representative local weather stations located nearby the community gardens. Further, land use data and crop types were surveyed in each community garden by direct interviews to "urban farmers". Irrigation methods, systems and water sources were also investigated by involving community garden managers and the Municipality Planning Department.

Then, Aquacrop was applied to collected data to assess the water footprint of urban agriculture in Rome, and results were statically analysed.

A series of choropleth maps reporting water footprint estimates were also created as communication tools to relevant stakeholders (i.e. planners, urban farmers, citizens). This type of product, in fact, may support current and future urban water policies following the concepts of sustainability.

Ruzica Stricevic :

Assessing the water footprint of apple orchards in Serbia to identify sustainable management options under present and future climate

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Keywords: apple orcharding, growing management option, climate change, blue and green water

The objective of the present research is to examine the upward blue water trend and the ratio of green to blue water under present and future climate conditions, as well as to recommend sustainable water management measures. Two apple growth approaches are also considered: orchards with and without grass on two locations Celarevo and Kragujevac. The blue water of apple, was conducted using CROPWAT 8.0 and the results of a relevant regional climate model – EBU-POM (Eta Belgrade University - Princeton Ocean Model) for climate scenarios A1B and A2 for the 20's (2010-2039); 50's (2040-2069) and 80's (2070-2099)).

The reference period for comparison was 1961-1990. During the reference period, the share of blue water was 0.49 in the orchard without grass, and 0.58 with grass, in Kragujevac. The share of blue water was higher in Celarevo, with 0.52 in the orchard without grass and 0.63 with grass. A slight increment is expected in the 20's, of 2 – 4%. A larger increment is predicted for the 50's at Kragujevac (up to 13%), than at Celarevo (3 – 4%). In the 80's, similar proportions of blue and green water are expected in both areas, 0.7 – 0.72 in orchards with grass and 0.63 – 0.66 without grass. In an orchard with grass, the demand for blue water will increase slightly, from the current 510 mm to 580 in the 20's, and up to 659 and 747 in the 50's and 80's, under A1B scenarios. However, under the A2 scenario a larger increment is expected in Kragujevac than in Celarevo.

An increment of up to 739 and 822 mm could be expected in Kragujevac, and up to 642 and 763 in Celarevo, in the 50's and 80's, respectively. The preferred option from a water management perspective is an orchard without grass. The largest increment of 70% of blue water, compared to the reference period (340 mm), could be reached in Kragujevac in the 80's. In this option, the demand for blue water would remain on the same level as blue water in the 20', in orchards with grass. This management practice would be favorable in plains. On slopes (erosion-prone areas), anti-hail nets should be considered, since the demand for blue water could be reduced by 20% to up to 40%.

Session II - Optimising water footprints of Catchments, 8th March 2016, 13.30-15.00

Leszek Hejduk :

The quality of water footprint estimation for catchment

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Keywords: water footprint, catchment scale, agriculture

According to Hoekstra et.al. (2011) the water footprint within a geographic area is defined as the total freshwater consumption and pollution within the boundaries of the area. The calculation of such footprint is actually a kind of water balance – virtual water balance. As a water footprint calculation is a substraction of gross import and gross export of virtual water for a particular area, it is possible do calculate it based on typical hydro-meteorological data.

The main problem is a detailedness of available data. For small catchments it is very difficult to gained detailed data about export and import of particular crops, so it is very difficult to estimate the water connected with it. In this paper, the attempt for calculation of water footprint has been conducted based on long term hydro-metrological data for small (area of 23.km2) agricultural catchment (Zagożdżonka river) in central Poland. Land use data were applied for estimation of water export for particular products. The discussion of the results focus on possible water footprint change due to land management change.

Hoekstra, Chapagin, Aldaya, Mekonnen. 2011. The Water Footprint Assessment Manual. Setting the Global Standard, Earthscan.

Claudia Brauer :

Simulating the effect of surface water management on soil moisture and vegetation on the catchment scale

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Keywords: rainfall-runoff model, crop growth model, water management, groundwater-surface water interactions

In many densely populated lowland areas worldwide, surface water levels are managed to make optimal use of the available water for crop production. Surface water is supplied and weirs installed to maintain high groundwater levels in summer and reduce drought stress in vegetation. When climate or the demand for agricultural products change, water management needs to be adapted. Water managers would benefit from a model which can simulate the effect of climate change and water management strategies on soil moisture and vegetation growth on the catchment scale, so they can make informed decisions about supplying water.

In this study, we couple a rainfall-runoff model to a vegetation model. The chosen rainfall-runoff model is the Wageningen Lowland Runoff Simulator (WALRUS), a recently developed, simple and fast model to simulate hydrological processes in areas with shallow groundwater. The simulated storage deficit is used as input for the vegetation model WOFOST, which simulates rooting depth, (water limited) crop growth and yield. The combined model WALRUS-WOFOST is computationally efficient, which makes it suitable for scenario analyses related to climate or water management or real time control.

WALRUS-WOFOST was tested in two catchments in which surface water is supplied upstream: the Cabauw polder and the Bakelse Aa catchment. The 0.5 km2 Cabauw polder is part of the Cabauw Experimental Site for Atmospheric Research (CESAR), where many additional measurements are available, such as soil moisture and actual evapotranspiration. The case study in the 90 km2 Bakelse Aa catchment demonstrates the practical applicability of WALRUS-WOFOST

Jasna Grabić :

Water footprint of supporting structures on agricultural land in the Vojvodina Province, Serbia

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Keywords: water surplus, grey water footprint, drainage, canal network, bio-drainage

Within the typical lowland agricultural area where plant production is dominant branch the biggest share of land is covered with cultivated plants, whereas the remaining part is under field roads and drainage canals (5-15%). These structures are supporting, but inevitable within an agricultural area and might have significant footprint on water – especially drainage canals.

Regulation of soil-water regime is crucial for successful crop production. While irrigation is a measure which supplies water to crops during periods when there is a deficit, drainage is as important measure that removes water surplus. Since in some regions excess water plays an important role in enabling stable and sustainable crop production, this aspect of water footprint (WF) has to be taken into account while concerning overall WF (e.g. whether widening the concept of the gray WF, or introducing a new aspect, maybe an "orange" WF).

The paper gives an example of WF of supporting structures on agricultural land in the Province of Vojvodina, the northern part of Serbia. In the province, thanks to land reclamation measures 70% (1.5 million ha) of this area has been transformed from permanent or seasonally endangered lands from water surplus into fertile farmland. During a century and a half a dense canal network has been established consisting of 960 km of huge canals of the Hydrosystem Danube-Tisa-Danube and around 20000 km of small canals draining water directly from fields. The major pressure is in spring when drainage prevents occurrence of water logging on fields. Apart for the drainage by canals, surplus water can be removed also by evaporation i.e. application of some plants planted along the supporting structures. The paper discusses both drainage methods in the context of the overall catchment footprint.

The other benefit of supporting structures can be seen in improving gray water quality, if along all structures (i.e. canal and field road networks) suitable vegetation is present. The vegetation retains a portion of nutrients and influences the degradation of some other water pollutants. Besides, proper management of vegetation is necessary in order to prevent becoming a nuisance. The paper provides a SWOT analysis of existing vegetation management measures of supporting structures within the overall catchment in the Province of Vojvodina. Finally, it proposes some new management measures which would lead to improvement of WF of supporting structures on catchment scale for the examined agricultural region.

Bojan Srdjevic :

Impact of surface reservoir control in hazard conditions on computing water footprint for orcharding

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Keywords: surface reservoir, hazard, orcharding, water footprint

Water resources systems with multiple purposes surface reservoirs are commonly operated over multi-year periods. In their nature reservoirs are no consumptive water users. Their waters are dynamically stored and released according to specified stationary control strategies and operational policies but waters are not consumed in (or by) reservoirs. At least, this is valid if no significant seepage occurs through the dams, or there is no large water infiltration into underground storage (e.g. aquifer), or no significant net-evaporation occurs from the reservoirs surfaces. Once water is released at reservoir outlets (e.g. through tunnels to the turbines for hydro-electric generation), or diverted for specific purpose (e.g. pumping water directly from the reservoir to drip irrigation system for orcharding), reservoir's waters receive measurable economic value which in turn may determine way how to compute footprint related to certain commodity, product or service.

As far reservoir operation is concerned, it is strongly dependent on hydro-meteorological conditions, stationary rule curves to be followed, operating policies related to simultaneous control of more reservoirs connected in tandems or cascades, available imports on demand, etc. Demands for water change from purpose to purpose, vary in time and usually the whole system is subjected to performance measurements such as its reliability, ability to assure firm waters, resiliency and vulnerability.

The paper discusses options in computing water footprint for produced fruits in orchards around specific reservoir. Based on use of stored reservoir waters only, and by respecting dynamic performance of the whole system, we explore options how to enable inclusion of hazards such as deficits of water which may affect facilitation of water deliveries due to resiliency and vulnerability of reservoir in long term, following stationary control strategies and dynamically adaptable operational policies at reservoir

Session III - Solutions to Improve Water Footprints, 8th March 2016, 13.30-15.00

Sebastian Multsch :

Determination of crop productivity curves in relation to salinity stress

Sebastian Multsch[1], Konrad Bestian[1], Thomas Michalik[1], Juliane Kellner[1], Abdulaziz.S. Alquwaizany[2], Omar A. Alharbi[2], Hans-Georg Frede[1], Lutz Breuer[1,3]

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Salinization of agriculture fields can highly impact the productivity of agriculture systems, in particular in semi-arid and arid regions where irrigation agriculture is based on local surface and groundwater resources. Salinity is management by means of leaching, i.e. salts are washed out from the soil by additional irrigation, to maintain a crop tolerable salt concentration in the rooting zone. The water required for salt leaching depends on the salinity of irrigation water, the irrigation technique and the crop specific salt tolerance. The latter one is often represented by crop productivity functions which relate the salt concentration of either soil solution or irrigation water to the relative yield of crops. Such functions are often implemented into crop water models to assess salinity stress. The most commonly applied guideline for managing salinity is proposed by the FAO29 Irrigation and Drainage paper which contains a comprehensive database on crop productivity functions from various experiments and other literature sources which are mostly based on experiments from the late 1970'ies. The objective of this work is to supplement the database and determine state of the art crop productivity functions. In a first step, the recent developments of salt tolerant crop types by conventional breeding and transgenic techniques have been investigated by a comprehensive literature survey on the relationship between salinity and crop yield resulting in 77 articles with 344 experiments. In a second step, crop productivity curves have been derived by breakpoint analysis in order to calculate crop productivity functions in relation to FAO29 guidelines where the relationship between crop yield and salinity is described by a two-component linear function. Moreover, other types of functions have been tested (e.g. sigmoidal-shaped) in order to improve the validity of this statistical approach. In future, these newly developed crop productivity curves will be implemented into a straight forward crop water balance model in order to determine the impact of improved crop salinity tolerance on the irrigation balance of field crops. This will in turn give an important measurement for improving water footprints in arid and semi-arid areas where salinization is a major determinant for agriculture productivity.

The authors gratefully acknowledge the support of the King Abdulaziz City for Science and Technology (KACST), Saudi Arabia, for funding the research Project No. 33-900 entitled ''Technology for desalinated seawater use in agriculture".

Eric Rendón Schneir :

The water footprint of Peruvian bananas in the Chira watershed: indicator of sustainable watershed development?

Eric Rendón Schneir[1], Andres Verzijl[2]

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Keywords: water foot print, organic bananas, peru, sullana, social productivity and acceptability

In 2015 the National Water Authority (ANA) of Peru presented a first report on the nation's Water Footprint "with the objective to be able to improve our understanding of the processes related to [(in)direct] water consumption and its relations to the geographical sites of production"; connecting sites where water was coming from to where it was going to. In that report, Water Footprint is an indicator of volumetric water consumption; but also of the impact on wider hydro-social relations which are local and site-specific. We present the Chira watershed as the setting to analyse these processes, relations and connected sites. Its headwaters are located in Ecuadorian paramos. The downstream part of the watershed is located on Peru's desert coast. In recent decades agricultural activity increased and shifted towards export crops, like table-grapes, biofuels, mangos and (organic) bananas. Production of the latter two crops are done by smallholders and exported, in principle to the Netherlands.

The paper consists of two parts. First, as an illustrative example, we analyse water use and footprint of organic and conventional banana cultivation of the Peruvian Province of Sullana, in the Chira watershed. Use is made of secondary data and CROPWAT 8.0. Water footprint calculations will indicate water volumes per hectare, per ton, per farmer, per gaining etc. for the period 2000-2014. The historic analysis demonstrates the response of both types to increased water scarcity. Furthermore, due to desert climate conditions, we do not consider a green water foot print.

The second part of the paper describes the socio-environmental relations and sites of the Chira watershed, which (given its conditions) offers a niche for smallholder organic fair trade production of bananas. Even if their water footprint is higher than conventional production, there are other impacts and indicators to consider for a sustainable watershed development such as the social productivity and acceptability of water consumption in the Chira watershed and the sites this water use is connected to. While consumptive water use of agro-industrial and export crops (sugar cane, grapes) maybe more productive than that of organic bananas or rice, the latter two crops can generate higher levels of employment and income for local farmers and workers in the organic fair trade associations (banana) or may be contributing to local food security (rice). Early results indicate each farmer, owning 0,8 hectare on average, generate full time employment for an additional family (with jobs like on-farm management, harvesting and processing for export).

Andres Verzijl :

Water Footprint's feet of clay? Peruvian smallholder irrigation realities in times of global water accountability

Carolina Domínguez Guzmán[1], Andres Verzijl[2], Margreet Zwarteveen[3]
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Keywords: water footprint, multiplicity, mango production, irrigation practices, Motupe, Peru

In the wake of Peru's agricultural modernization and export boom, governmental agencies, companies and NGOs have actively embraced the notions of virtual water and water footprint. These mechanisms to (economically) measure and calculate water consumption of agro-export products (and producers) are quickly becoming emblems of good water governance and responsible water management in the country. We argue that water footprint and water accountability also lead to the reification of local water realities and the multiple ways of relating to water that cannot be calculated or easily made legible. These therefore, risk being misunderstood or excluded when translated into water managerial strategies, policy standards and certifications – as we demonstrate in this paper.

In the logic of water footprint accounting, water appears as a singular object of epistemology; that produces a particular kind of knowledge of water as universal, transferable and calculable. We suggest, however, there are not only ways of knowing water as an object of study, but rather ways of practicing or doing water and relating to it. This shift to ontological multiplicity can help to show how water is enacted through the different practices and relations that people have with it; from which calculation and water accounting is one of many.

Using praxiography of smallholder irrigation of fresh mangos exported from the valley of Motupe in Northern Peru, we analyze how the water footprint concept transforms, travels and interferes with other water practices, that are questioned or undermined but which account for the majority of mango export in Peru. These smallholder practices are associated to intercropping, favorable climate and bricolage tactics of marginal groups that optimize their water use and access in ways that may escape a water footprint logic. This does not point to a shortcoming of water footprint as a quantitative indicator, but shows the limits of a singular representation of the complex and messy local water setting. We conclude by emphasizing the need for interdisciplinary collaboration that helps building a common ground based on different waters to engage with the study of complex water problems.

Davy Vanham :

Cities as hotspots of indirect water consumption: the case study of Hong Kong

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Keywords: water footprint, urban, Hong Kong, city, diet

During the last years, the city of Hong Kong has made large investments to make its urban water supply system more water efficient and sustainable. As such, its municipal water abstraction – often defined as direct water use – has decreased from 355 litres per capita per day (l/cap/d) in 2005 to 326 l/cap/d in 2013. Due to its political history, Hong Kong is unique in the world in data availability on urban food consumption. It is therefore the ideal case study to show typical urban food consumption behaviour and its related indirect water use.

The current average diet in Hong Kong is very different to the average Chinese diet. It is characterised by a high intake of water intensive products like animal products and sugar, leading to a food related indirect water use or water footprint (WFcons) of 4483 l/cap/d. According to recommendations from the Chinese Nutrition Society for a healthy diet, the intake of some product groups should be increased (vegetables and fruit) and of other product groups reduced (sugar, crop oils, meat and animal fats). This would result in a reduction of the WFcons of 32% to 3064 l/cap/d. Especially the recommended reduced intake of meat from 79 kg per capita per year (kg/cap/yr) to 22 kg/cap/yr would result in a substantial WFcons reduction.

A pesco-vegetarian diet would result in a reduction of 41% (to 2667 l/cap/d) and a vegetarian diet in a 54% (to 2042 l/cap/d) reduction. Hong Kong citizens can thus save a lot of water by looking at their indirect water use, through a change in their diet. In order to become sustainable, (mega)cities should reduce their dependency on distant resources and ecosystems.

Second Plenary Session 8th March 2016: 15.30-17.00

Ruth Matthews :

Achieving water sustainability in business and beyond through water footprint assessment

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Freshwater scarcity manifests itself in the form of declining groundwater tables, reduced river flows, shrinking lakes and heavily polluted waters, but also in the increasing costs of supply and treatment, intermittent supplies and conflicts over water. This poses a risk to businesses, affecting operations and supply chains.

Water Footprint Assessment (WFA) offers a new perspective to businesses to understand their water footprint and identify the key strategies to make it sustainable, efficient and equitable. WFA provides a consistent and comprehensive framework to understand water dependencies in operations and across supply chain, to assess sustainability and formulate responses, which are essential in the water stewardship journey of a business. Water stewardship is a collaborative and multi-stakeholder approach that aims to achieve social, environmental and economic benefits. WFA corresponds to all steps of water stewardship: establishing a sound foundation of quantitative analysis, developing a water strategy, setting efficiency targets, designing an implementation plan and monitoring and evaluation. WFA can also support watershed level collective action, the formation of public policy, stakeholder and community engagement, transparency and comprehensive water reporting.

For example, water footprint (WF) benchmarks can be used to determine water consumption and reduction targets and promoting water efficiency in operations and supply chain. Watershed level WFAs can support business to address local water sustainability and water risks because water scarcity and pollution differs from one watershed to another. WFA further supports civil society engagement in river basin dialogues by building their understanding of the issues and it assists government in having a comprehensive picture of water use within the basin. Examples of engagement with businesses and government in WFA will be presented and lesson learnt shared.

Gerardo van Halsema :

The need for a global perspective to address increasing demands for water and food

Petra Hellegers, Pieter van Oel and Gerardo van Halsema
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Local water resources worldwide are increasingly influenced by global forces, including changes in climate and water use. International trade in food crops affects local water resources worldwide. Consumers of water-intensive products do not take into account the potentially negative effect of their consumption on water resources elsewhere. Moreover, it is unclear who is responsible, what to do about it and at which scale.

In general it remains unclear how to effectively cope with water scarcity at different spatial levels. There are multiple reasons to carefully evaluate the potential of local and system level response-options. In recent decades water productivities have improved substantially, mainly due to agronomic improvements. Today, water productivity is already high in the most productive regions. No large additional gains are foreseen. Also gains in yield per unit of land do not necessarily coincide with water productivity gains, as farmers usually maximise returns on land rather than on water. More importantly, enabling conditions for farmers and water managers to enhance water productivity are not in place.

At basin level, conflicts over water (re)allocation hinder cooperation on food production. Subsidies, foreign exchange shortages, reluctance to rely on foreign supplies, and presence of other powerful domestic forces all explain why international trade is often not steered by water scarcity. Besides fluctuating prices of food staples trigger countries to review their food policy in favour of increased self-sufficiency. Such considerations add political and social dimensions to the narrow economic rationale of food trade (which is in favour of specialisation in export crops with a high economic return in water-scarce regions).

Other factors that affect the priority of national policies to specialize in high value crops are the level of integration of countries in the global economy, access to markets through trade agreements and confidence in the global market for access to staple food. This means that factors outside of the water domain play an important role. Worldwide there is currently also still an underutilized vast forgotten potential of rainfed agriculture. Many of these areas in Africa, such as upstream areas of the Nile Basin have, however, been destabilized by recent war and civil unrest. Stabilizing them and strengthening intra-basin cooperation via food trade seem to be better strategies than water reallocation. So a global perspective is required that also focuses on factors outside the water domain. This implies that the scope of water resources management needs to be broadened.

Annex A. Detailed schedule of Conference Programme

Final EURO-AGRIWAT Conference, 7-9 March 2016, Wageningen

Sunday 6 March

17.00-18.00 Informal get-together at Grandcafé Loburg, Molenstraat 6, Wageningen (http://www.loburg.com/contact)

Mondag 7 March

Time	Keynote / Parallel Sessions - session leader - room number - author (speaker): title -			
9.00	**Registration with coffee and tea**			
9.30	**Plenary session - Pytrik Reidsma - C1005**			
9.30	Opening by Bram de Vos			
9.40	Anna Dalla Marta: Objectives and conclusions "Assessment of EUROpean AGRIculture WATer use and trade under climate change"			
10.00	Arjen Hoekstra: Water Footprint Assessment: an evolving research field			
10.30	Elías Fereres: Addressing the complexities in the relation between water and food production: avoiding too simplistic views, and future prospects			
11.00	**Coffee and tea break**			
11.30	**Plenary session - Hong Yang - C1005**			
11.30	Christian Kersebaum: Assessment of crop water footprints under present and future climatic conditions			
11.50	Christos Zoumides: Virtual water trade: an overview of applications and implications			
12.10	Filiberto Altobelli: Assessment of management and adaptation options for the sustainable management of Water Foot Prints			
12.30	Leonidas Toulios: Using remote sensing for assessing water footprints			
12.50	**Lunch break**			
14.00	**Session I - Kersebaum - C3015 Assessment of crop water footprints under present and future climatic conditions**	**Session II - Zoumides - C3016** **Water footprints, sustainability and virtual water trade**	**Session III - Toulios - C3020** **Remote sensing of agricultural water footprint**	
	Anne Gobin: Variability in the water footprint of arable crop production across European regions	Carole Dalin: Who is eating up the world's aquifers?	Marios Spiliotopoulos: The use of Earth Observation methods for estimating regional Crop vapotranspiration and Yield for Water Foot Print accounting	
	Pavol Nejedlik: Water use efficiency and water footprint of selected crops. A case study – Slovakia	Pirjo Peltonen-Sainio: Water-Smart-Agriculture to Cope with Changing Climate at High Latitudes	Oscar Hartogensis: New Development in Scintillometry: Direct Measurement of Evapotranspiration at Field- to Regional Scales	

	Alejandro Blas: Comparison of water footprints of Mediterranean and American diets	Bosko Blagojevic: Cooperative allocation of blue WaterFootprint benefits	Piotr Struzik: Limitation of water availability for crops, monitored by satellite products during 2015 drought in Poland	
	Ángel de Miguel: The water footprint of agriculture in Duero river basin	Bosko Blagojevic: Defining land suitability for irrigation based on water use efficiency: a case study from Vojvodina Province (Serbia)		
15.30	**Coffee and tea break**			
16.00	**Session I - Kroes - C3015** **Assessment of crop water footprints under present and future climatic conditions**	**Session II - Blagojevic - C3016** **Water footprints, sustainability and virtual water trade**	**Session III - Gobin - C3020** **Remote sensing of agricultural water footprint**	**Session IV - Reidsma - C3030** **Grey water footprints**
	Domenico Ventrella: Green and blue water footprint of winter wheat cultivation at regional scale in two European case-studies	Petra Hellegers: The need for a global perspective to address increasing demands for water and food	Filiberto Altobelli: Assessment of the long-term variability of green water footprint with EO-based irrigation advisory services dataset	Hong Yang: Assessment of global grey water footprint of major food crops
	Rick Hogeboom: Modelling water footprints of crop production on an annual basis using AquaCrop: the case of wheat in China	Jeroen Vos: From universal to contextualized water footprint conceptualizations	Marios Spiliotopoulos: Crop coefficients assessment using METRIC model and relationships with Landsat's TM thermal channel under stress conditions in central Ireland	Johannes Deelstra: Agriculture and the grey water footprint; a case study for Norway.
	Dr. Muhammad Anjum Iqbal: Assessment of green water footprints for winter wheat production under present climatic conditions	Frank Niele: Water-related business risk assessment in the oil & gas industry	Gheorghe Stancalie: Satellite based vegetation indices and biophysical parameters for the assessment of the water footprint of crops	Abebe Demissie Chukalla: Effect of fertilizer strategies on the grey water footprint of irrigated crop production
	Nazli Koseoglu: The water footprint of the Scotch malt whisky industry	Ayşe Özge Demir: The Importance of the Water Footprint of Animal Fibers Production in Turkey		Lutz Breuer: Determination of grey water footprints for salinity control with a model inter-comparison and GLUE analysis
				Ana Tarquis: Agronomic concepts of grey water footprint. A case study in a fertirrigated melon crop under semiarid conditions.
17.30	**Drinks and bites**			
18.00	**Buffet**			

Tuesday 8 March

Time	Keynote / Parallel Sessions - session leader - room number - author (speaker): title -			
9.00	**Plenary session - Pieter van Oel - C1005**			
9.00	Martin van Ittersum: Global yield gap atlas and water use efficiencies			
9.30	Huub Rijnaarts: From virtual water to circular water concepts			
10.00	Jay Lund: Water resources and environmental system engineering			
10.30	**Coffee and tea break**			
11.00	**Session I - Heinen - C3015** **Assessment of crop water footprints under present and future climatic conditions**	**Session II - Altobelli - C3016** **Water footprints, sustainability and virtual water trade**	**Session III - Hellegers - C3033** **Solutions to improve water footprints**	**Session IV - Dona Barirani & Abebe Demissie Chukalla - C3030** **River Basin Game**
	Josef Eitzinger: Crop water footprints under complex climatological conditions - case study of Austria.	Davy Vanham: Does the water footprint concept provide relevant information to address the water-food-energy-ecosystem nexus?	Pieter van Oel: How to use proposed water footprint and water productivity benchmarks for crop production?	In this game the participants take roles of farmers in the three compartments (upstream, midstream and downstream settings). These farmers try to optimize their benefits by irrigating their fields while water is the limiting factor. The participants will learn about 'the tragedy of the commons', about cooperation, free-rider behaviour and upstream-downstream effects. They experience the risk of over-abstractions of water in a river basin and learn how this risk relates to the complexity of the system, the conflict between individual and group optimums and the difficulty in achieving good cooperation.
	Jüri Kadaja: Potential green and blue water footprints of potato in Estonia.	Eleanor Murphy: Water Footprinting of Milk Production Systems in Ireland	Mats Lannerstad: A new approach to consistently assess and compare water use across the global food system	
	Laura Miguel Ayala: Impact of soybean expansion on water Footprint in the Amazon under climate change scenarios	Ayşe Özge Demir: An Evaluation on Water Footprint of Small Ruminants in Turkey	Ylva Ran: Producing food for humans – from crops or animals? Tackling competition for freshwater use between crop and animal production	
	Francesca Natali: Computing crops water footprint for economic and agronomic sustainability: experiences from Europe and Israel	Ridha Ibidhi: Water, land and carbon footprints of lamb and chicken meat raised in Tunisia under different farming systems: A comparative study	Sebastian Multsch: Optimization of desalinated seawater use in irrigation agriculture by a coupled crop water-economic modelling approach	
12.30	**Lunch break**			
13.30	**Session I - Eitzinger - C3015** **Assessment of crop water footprints under present and future climatic conditions**	**Session II - Moors - C3016** **Optimising water footprints of catchments**	**Session III - Van Oel - C3033** **Solutions to improve water footprints**	**Session IV - Dona Barirani & Abebe Demissie Chukalla - C3030** **River Basin Game**

<table>
<tr><td></td><td>Christos Tsadilas: Industrial tomato cultivation water footprint in Pinios river basin. Soil properties interactions</td><td>Leszek Hejduk: The quality of water footprint estimation for catchment based on hydrological data</td><td>Sebastian Multsch: Determination of crop productivity curves in relation to salinity stress</td><td rowspan="4">In this game the participants take roles of farmers in the three compartments (upstream, midstream and downstream settings). These farmers try to optimize their benefits by irrigating their fields while water is the limiting factor. The participants will learn about 'the tragedy of the commons', about cooperation, free-rider behaviour and upstream-downstream effects. They experience the risk of over-abstractions of water in a river basin and learn how this risk relates to the complexity of the system, the conflict between individual and group optimums and the difficulty in achieving good cooperation.</td></tr>
<tr><td></td><td>Roel Helmes: Life cycle water demands of four horticultural crops in the context of zeolite based pesticide application</td><td>Claudia Brauer: Simulating the effect of surface water management on soil moisture and vegetation on the catchment scale</td><td>Eric Rendón Schneir: The Water Footprint of Peruvian bananas in the Chira Watershed: indicator of sustainable watershed development?</td></tr>
<tr><td></td><td>Anna Dalla Marta: Assessment of water footprint of urban agriculture in Rome, Italy</td><td>Jasna Grabić: Water Footprint of Supporting Structures on Agricultural Land in the Vojvodina Province, Serbia</td><td>Andres Verzijl: Water Footprint's feet of clay? Peruvian smallholder irrigation realities in times of global water accountability</td></tr>
<tr><td></td><td>Ruzica Stricevic: Assessing the water footprint of apple orchards in Serbia to identigy sustainable management options under present and future climate conditions</td><td>Bojan Srdjevic: Impact of surface reservoir control in hazard conditions on computing water footprint for orcharding</td><td>Davy Vanham: Cities as hotspots of indirect water consumption: the case study of Hong Kong</td></tr>
<tr><td>15.00</td><td colspan="4">Coffee and tea break</td></tr>
<tr><td>15.30</td><td colspan="4">Plenary session - Anna Dalla Marta - C1005</td></tr>
<tr><td>15.30</td><td colspan="4">Ruth Matthews (Water Footprint Network)</td></tr>
<tr><td>16.00</td><td colspan="4">Gerardo van Halsema:
Future challenges in water footprint research</td></tr>
<tr><td>16.30</td><td colspan="4">Discussion & Conclusions</td></tr>
<tr><td>17.00</td><td colspan="4">Drinks and bites</td></tr>
<tr><td>18.00</td><td colspan="4">Buffet</td></tr>
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Wednesday 9 March

<table>
<tr><td>8.15</td><td>Excursion to the water board "Rivierenland"

Assemble at Droevendaalsesteeg between building 107 (Radix) and 102 (Forum), see map</td><td>9.00</td><td>Excursion in and around Wageningen Campus
• AlgaePARC
• Kraijenhoff van de Leur Laboratory for Water and Sediment Dynamics
• ISRIC World Soil Museum

Assemble in the lobby of the Lumen/Gaia building (building 100/101), Droevendaalsesteeg 3, see map</td></tr>
<tr><td>13.15</td><td colspan="3">Lunch at the Restaurant of the Future</td></tr>
<tr><td>14.00</td><td colspan="3">End of conference</td></tr>
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