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Original Research Article

SHui, an EU-Chinese cooperative project to optimize soil and water management in agricultural areas in the XXI century

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ABSTRACT

This article outlines the major scientific objectives of the SHui project that seeks to optimize soil and water use in agricultural systems in the EU and China, by considering major current scientific challenges in this area. SHui (for Soil Hydrology research platform underpinning innovation to manage water scarcity in European and Chinese cropping systems) is large cooperative project that aims to provide significant advances through transdisciplinary research at multiple scales (plot, field, catchment and region). This paper explains our research platform of long-term experiments established at plot scale, approaches taken to integrate crop and hydrological models at field scale; coupled crop models and satellite-based observations at regional scales; decision support systems for specific farming situations; and the integration of these technologies to provide policy recommendations through socio-economic analysis of the impact of soil and water saving technologies. It also outlines the training of stakeholders to develop a basic common curriculum despite the subject being distributed across different disciplines and professions. As such, this article provides a review of major challenges for improving soil and water use in EU and China as well as information about the potential to access information made available by SHui, and to allow others to engage with the project.

1. Introduction

Agriculture must address a major global societal challenge in the coming decades. It must ensure food and nutritional security, together with improved resource efficiency while facing climate

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change. Feeding a projected global population of over 9 billion by the year 2050 will require a 60% increase in global agricultural production relative to 2005 (OECD-FAO, 2015) to reduce poverty, raise dietary standards and enhance food security. The EU and China currently host 25% of the world's population and together produced 31% of the world's cereal in 2014 (World Bank, 2019). Increasing agricultural production while preserving soil and water resources in the EU and China is thus of paramount regional and global relevance.

Globally, water resources are under heavy stress which affects both food security and environmental sustainability. In many areas of Europe and China, crop production is already water-limited and will be more so in the future due to climate change and to increased competition for water from other sectors of society (Huang, Zhong, Ridoutt, Huang, & Li, 2015; Kovats et al., 2014). Irrigated agriculture represents about 20% of the cultivated land, but contributes for about 40% of global food production (FAOSTAT, 2019). Any increase in agricultural production from irrigated areas must rely on more efficient water use and alternative water sources. Moreover, since rainfed systems comprise approximately 90% of the cultivated land in the EU and China (World Bank, 2019), enhanced crop use of rain water is needed to boost yields. Approximately 62% of total precipitation over land infiltrates into the soil and is taken up by natural vegetation and crops (Allan, 2011). The remainder is lost as runoff, which brings the potential of water-mediated soil erosion.

For this reason, the first action needed to maintain the water holding capacity of soils is to control soil erosion. Globally, an estimated 75% of the utilized agricultural area is affected to some degree by soil erosion by water, of which almost 20% is above the maximum tolerable level soil loss which, depending on the local conditions, is in the range of 2–12 t/ha year (UNEP, 2012). In the EU, 12.7% of cropland ($14x10^6$ ha) is burdened with soil losses greater than tolerable levels (Panagos et al., 2015). In China, $36.3x10^6$ ha of land is estimated to suffer high erosion rates (Enming, Yi, Zhiyun, & Xinxiao, 2015). Climate projections for the coming decades suggest drastic changes in rainfall amounts and intensity in both continents, thereby affecting soil water availability and erosion. These climate changes are predicted to decrease Chinese maize yields by up to 35% (Tao & Zhang, 2011), and Mediterranean cereal yields by up to 10% (Iglesias, Garrote, Quiroga, & Moneo, 2012). All these studies predict an increased frequency of severe events (e.g. heat waves, dry spells, severe storms) which will also affect agricultural yields.

The challenge of increasing agricultural production in the EU and China, while at the same time conserving their resource base, is recognized by comprehensive EU and Chinese initiatives, such as EIP-AGRI Focus Group for Water & Agriculture (EIP-AGRI, 2016), EU-China 2020 Strategic Agenda for Cooperation (EEAS, 2017), and China's 13th 5-year plan 2016–2020 (PRC, 2017). Success will require optimal use of scarce soil and water resources at two fundamental levels, in-field (where the individual farmer is the decision maker) and aggregated larger scales, hereafter referred to as regional (such as irrigation district or catchments), where the decision making process involves a larger number and typologies of stakeholders. Generating and processing new knowledge is necessary at both scales and this knowledge must be fully connected in the decision-making process. Moreover, expertise from different scientific and technical disciplines, among them agronomy, irrigation technology, digital agriculture, hydrology, soil and water conservation, remote sensing, plant physiology, soil science and socio-economics, needs to be fully integrated. This rationale has led to formation of the SHui consortium pairing expertise across these disciplines, and within cognate cropping systems, between EU and China.

This is the overall aim of the 4-year (2018–2022) SHui project, co-funded by the European Union and the Chinese Ministry of Science and Technology (MOST) under the H2020 program. This project, whose overall approach is summarized in Fig. 1, aims to deliver a suite of technologies and tools to empower individuals and stakeholder organizations to make informed decisions to manage water scarcity in European and Chinese cropping systems, consolidating an integrated research platform for the coming decade across EU and China. This manuscript critically discusses the scientific and social challenges addressed by its different work-packages, in an attempt to allow and develop collaborations beyond the immediate consortium members.

2. Project components

2.1. Platform of long-term experiments

To reliably use and apply simulation models, necessary input data as well as measurements and observations for calibration and validation have to be available. Several databases already exist such as the Long-term Ecosystem Research in Europe (LTER), International Soil Carbon Network (ISCN), European Soil Data Centre (ESDAC), International Soil Moisture Network, USGS Water Data for the Nation, and Sustaining the Earth's Watersheds, Agricultural Research Data System (STEWARDS). Although they provide valuable data for managing soil and water resources, none includes a comprehensive set of data linking soil, water movement and crop growth at different scales with various agricultural systems. Furthermore, the required input data for hydrological or crop models are not available in many cases, or the data are provided in different, incompatible formats according to stakeholder needs.

A main objective of SHui is to develop and maintain an open data platform (ODP) for sharing long-term data on agricultural production, crop yield, soil properties, soil quality, water quality, and weather reflecting the climatic and cropping diversity within both Europe and China. The ODP will contain data collected at 26 stations in EU, Israel and China (Fig. 2, and Tables 1 and 2). The ODP includes ground-truthed data of existing long-term field observations as well as data generated in continuing experiments within SHui. Data are provided in a consistent format (1) to facilitate crop growth and hydrological modeling, (2) to develop algorithms and decision support systems, and (3) to validate the large regional modeling and information used by the socio-economic analysis.

Data requirements strongly depend on the type of model intended to be applied. For instance, models to assess soil erosion and water quality need other inputs than crop simulation models used to predict water use and crop yield. Furthermore, different models – even when designed to simulate the same process – are based on different approaches, that can be, for example, process-based (physical), empirical (stochastic), or hybrid "concept-based". Hence, each model requires specific input data, of which some are of fundamental importance for modelling. As a first step, it was necessary to identify minimum requirements for input data for simulation models. On this basis, templates were generated in csv-format based on feedback of research site operators regarding available characterizing data as well as measured data. Table 3 gives an overview of database structure and contents. Guidelines help providers to properly insert their data into the templates and upload them including relevant information of the experimental site (meta data). The guidelines as well as online descriptions help potential users to find data of interest and interpret them properly.

To obtain appropriate and adequate data sets for developing advanced sustainable technologies for soil water management, it is necessary to assure quality control. This includes that the supplied data have to fit for model development, decision making, and planning in the context of improving soil quality and water use

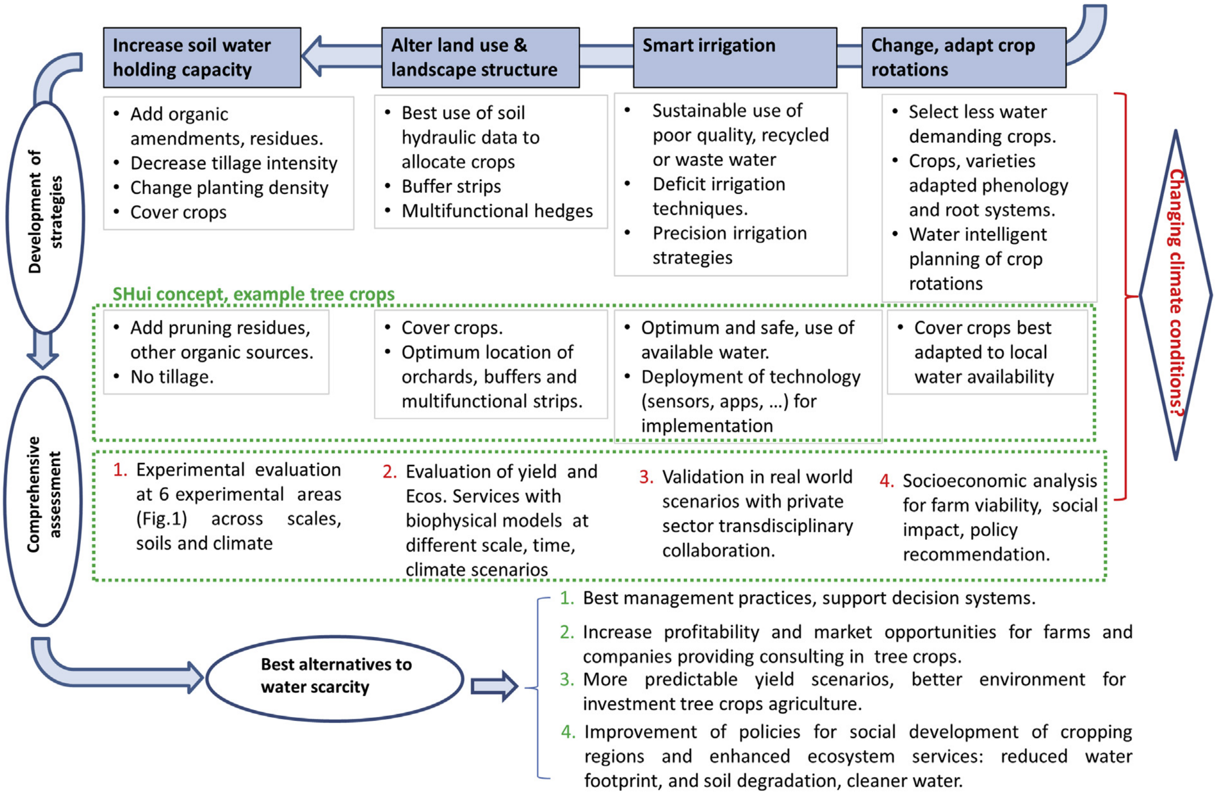

Fig. 1. Overall approach adopted within the SHui project.

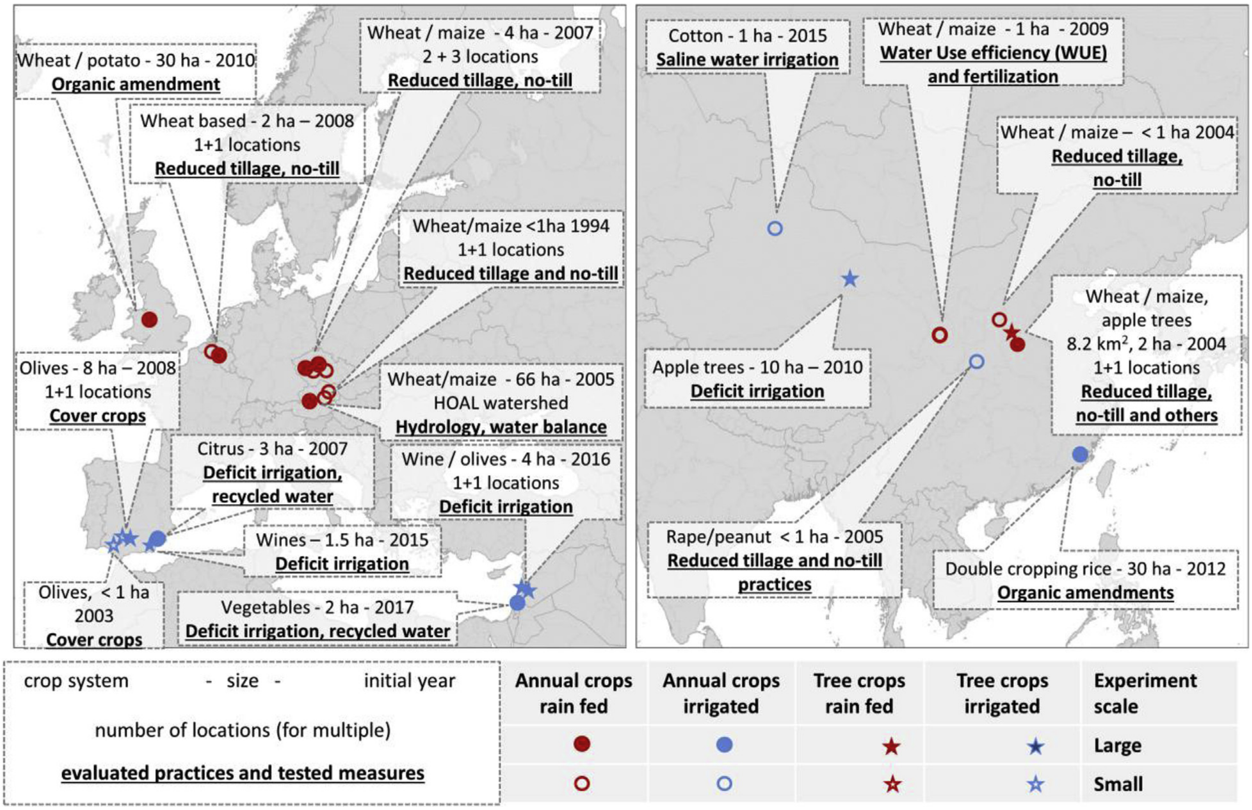

Fig. 2. Location and description of the experimental areas in the research platform.

Table 1
Summary of location, climate, crops and experimental information available across experimental platform. * Latitude of central point of the region covered by the experiments. **Agricultural system represented: TC Tree crops, CR cereal based rotations, V vegetables, C cotton. *** Köppen climate classification: Csa hot summer Mediterranean, Dwa monsoon-influenced hot-summer humid continental, Cfb temperate oceanic, Bwk cool desert, Cfa humid subtropical (no dry season), Dwb dry winter continental, Bsn mild semi-arid.

# Partner	Location, latitude*	Ag. System**	Climate***	Experimental field-plot/year
1 CSIC	S and SW Spain, 37.8ºN	TC	Csa	262
2 ARO	Israel 31.8° N	TC, CR, V	Csa	248
3 BJFU	NE China, 39.2° N	TC,CR,V	Dwa	1365
5 BOKU	Lower Austria, 48.4° N	CR	Cfb	378
6 CAU	NW China, 42.4 ºN	C	Bwk	432
7 CRSRI	W China, 30.5° N	T,CR	Cfa	180
9 CVUT	Czech R. 49.8 to 50.3ºN	CR	Cfb	141
10- FAFU	NW China, 35.8ºN	T	Dwb	80
14 NWAFU	Loess Plateau, China36.9ªN	T,CR	Bsn	2020
19 ULANC	N England, 54.9 ºN	CR	Cfb	25

efficiency. Therefore, each data file is checked for outliers and integrity before it is released in the ODP. Gap filling might be done by data providers, but then the method has to be indicated in connection with the data set. For filling sporadic gaps using information from time-adjacent values of the same location, it is suggested to use a combination of strict local average with the sample mean as described in Pappas, Papalexiou, and Koutsoyiannis (2014). After quality control and gap filling, the uploaded data series are released for all users. This will be done only in case that this gap filling is robust, e.g. for filling gaps in data with clear trend as daily temperature. Otherwise, the gap will be indicated to allow future user which might be the best strategy form them to use the raw data, The research platform and all corresponding documents like data templates and guidelines are available as final version under http://shui.boku.ac.at/shui/public/. Access is dependent on pre-registration through the main SHui web site at https://www.shui-eu.org. This is a platform which insures that no additional software is necessary for accessing the data. Two accessibility level are encompassed.

Level A: It will include a full description of the experiment regarding location, soil and climate type, objectives, hypothesis tested and specific treatments. It will also include the summary annual results of the experiment for as many years as possible. This level will be compulsory and open form all the sites included in SHui.

Level B: It will encompass the detailed records, e.g. event rainfall, runoff and erosion records, ... for the sites. It will be decision of the responsible team at each site, owner of the data, to make them freely accessible or to indicate the level of restriction to its access as in line with the decision made in WP1.

To ensure that the data gathered in the SHui project can be made available for re-use, the datasets will be released under a license that allows datasets to be re-used and new work to be derived from them. Partners are being advised about appropriate licensing schemes and license attributions to facilitate data re-use and ability to derive new work from the data and make these works open access. For this reason Attribution-ShareAlike (CC BY-SA) license is the SHui's encouraged license: Since it lets others remix, tweak, and build upon your work even for commercial purposes, as long as they credit the data generator and license their new creations under the identical terms. This is, for instance, the license used by Wikipedia.

2.2. Integrating crop and hydrologic modelling challenges at field scale

Modeling the behavior of crops and of hydrological systems is a very important component of SHui. Simulation models are excellent tools for scenario analyses, hypothesis testing, and identifying research needs, among many other applications. The philosophy of SHui is to generate novel tools to explore alternative management scenarios at different spatial scales. SHui has focused on expanding the use of the crop simulation model AquaCrop (Steduto, Hsiao, Raes, & Fereres, 2009) at field scale to the different crops and environments within the project. A particular challenge lies in scaling up point simulations to the plot and small catchment scales. Crop models tend to provide point simulations and are not amenable to scaling up, while hydrologic models operating at higher scales may provide the framework for integrating the crop simulations.

AquaCrop is a water-driven crop simulation model, differing from other well-established crop models, e.g. BOSFOST (de Wit et al., 2018) which are radiation-driven. Since its initial publication (Steduto et al., 2009), AquaCrop has been thoroughly tested and additional crops have continuously been added to its database. SHui will not only calibrate and validate the model for different environments, but seeks to implement several improvements to enhance its future use. Since AquaCrop is currently limited to the major annual herbaceous crops (Steduto, Hsiao, Fereres, & Raes, 2012), additional herbaceous crops (e.g. groundnuts) will be parameterized and an approach to simulate perennial crops such as alfalfa and other pastures will be developed. Additionally, alternative ways to reduce the empiricisms inherent in simulating the harvestable fraction of the biomass produced will be explored. Further anticipated improvements include enhancing the robustness of the soil water module, for instance to better describe soil salinity, and the treatment of how transpiration is converted into biomass via normalized water productivity.

SHui will address the challenge of producing a functional model of the yield responses of water-limited fruit tree crops, since description of their agronomic and physiological responses to water deficit is relatively scant relative to the knowledge base developed for the major herbaceous crops. SHui will take a pragmatic approach to predict how reducing crop water supplies below the maximum crop needs affects yields. The model, with a daily time step, will concentrate on simulating actual transpiration and will have a soil water module with two compartments, since most orchards are irrigated by localized methods (Green, Clothier, & McLeod, 1997) and heterogeneity in soil water content should be modelled (e.g. Huber et al., 2014).

A fundamental task is to identify options to add multi-dimensionality to crop simulation tools to upscale simulations from point to field scale. Multi-dimensionality allows simulation of lateral fluxes and the actual soil-water interactions between adjoining soil compartments, better reflecting soil moisture dynamics in the real world. Thus, one objective will be to simulate

Table 2
Summary of the field experiments contributed by the different partners to the experimental platform.*Year of start of operation.

# Partner	Experiment	Starting*	Brief description.
1 CSIC	1 Seville	2003	Measurement of runoff and sediment losses and soil properties under different soil management (bare soil cover crops) in deficit irrigated olive trees. Six plots, 480m^2.
	2 Cordoba I	2005	Measurement of runoff and sediment losses and soil properties under different soil management (bare soil cover crops) in deficit irrigated olive trees at different scales. One 8 ha catchment, 6 plots 288 m^2.
	3 Cordoba II	2013	Measurement of yield, water balance and tree development under four different soil management (two with cover crops and two with tillage in olive trees. Twelve plots, 162 m^2.
	4 Murcia I	2007	Measurement of citrus trees performance in response to different regulated deficit irrigation regimes and water salinity levels. Eight plots, 250 m^2..
	5 Murcia II	2016	Experiments on five different strategies of deficit irrigation in grapevines (including rainfed with only emergency irrigation) deficit irrigation using water of different quality. Twenty four plots 200 m^2 each within an irrigation district of 1400 ha also monitored.
2 ARO	1 Western Negev	2016	Experiments water demand and irrigation for four year cereal based rotation: potato, wheat/barley, peanut, wheat/barley, carrot/radish, corn/sweet potato, with data on crop, water use, yields and yield and mapping of soil properties. Sixty four plots, 625 m^2 each.
	2-Gilat I	2016	Experiment on potato, corn and cotton rotations to determine optimum N to irrigation water quality (salinity) and to measure (and then model) groundwater risk of agricultural management. Twenty plots, 250 m^2.
	3 Gilat II	2017	Experiment on crop water response for a rotation on irrigated and rain fed (including corn, potato, cotton, peanuts, wheat/barley). Measurement of soil water use, yield and plant water status will be monitored. Four plots, 6.25 ha.
	4 Jerusalem	2016	Experiment on grapevines to use precision irrigation in small blocks adapting irrigation to spatial variability of soil properties to optimize water use and increase yield and quality. Twenty plots, 1000 m^2.
	5 N. Israel	2016	Experiment on peaches to use precision irrigation in small blocks adapting irrigation to spatial variability of soil properties to optimize water use and increase yield and quality. Twenty plots, 1000 m^2.
3 BJFU	1 Beijing I	2005	Experiments on water demand and leaching on irrigated (using unconventional water sources) and rainfed rotations with cereals and field vegetables. One hundred plots with sizes from 40 to 100 m^2.
	2 Beijing II	2012	Experiment on water use by tree crops (pear, apple, cherry, vines) in 4 locations in different Beijing districts. Seventy three plots 9 m^2.
5 BOKU	1 Lower Austria I	1995	Measurement of runoff and sediment losses and yield with different soil conservation practices on cereals at three different locations in Lower Austria. Nine plots 60m^2.
	2 Lower Austria II	2005	Measurement of the impact on crop yield of different soil conservation practices on cereals at three different locations in Lower Austria. Nine plots 320 m^2.
	3 Petzenkirchen	1945	Fully equipped experimental catchment in a field crops farmland to measure all the components of the water balance, as well as full description of farm management and yield. One 66 ha catchment.

(*continued on next page*)

Table 2 (*continued*)

# Partner	Experiment	Starting*	Brief description.
# Partner	Experiment	Starting*	Brief description
6 CAU	1 Shawan I	2012	Evaluation of different deficit irrigation strategies in cotton on saline soil, including determination of plant physiological variables. Eighteen plots, $18 m^2$.
	2 Shawan II	2012	Evaluation of the effect of different deficit irrigation strategies combined with different rates of nitrogen fertilization on plant growth and components of the water balance in cotton on saline soil. Twenty seven plots, $40 m^2$.
7 CRSRI	1 Zhangjiachong	2003	Measurement of components of the hydrological cycle within the catchment with a land use of tree crops (apples, pears) and cereals. Soil management and yield data are available within the catchment and plots. One watershed 16200 ha and 14 plots, 220 m^2.
9 CVUT	1 Nucice	2003	Measurement of water balance, runoff, sediment losses and yield in a farm with cereals based rotation under conservation agriculture. One 53 ha catchment.
	2 Bykovice	2002	Measurement of soil degradation by erosion, volumetric analyses of erosion rills, sediment losses and yields at different scales in a farm with cereals based rotation under conventional agriculture. 9 km^2 catchment and rainfall simulation campaigns.
	3 Risuty	2014	Measurement of runoff, sediment losses and yield at different scales in a farm with cereals based rotation under conservation agriculture. One 200 ha catchment and eight runoff plots 50.4 m2.
10 FAFU	1 Yangling	2001	Measurement of apple tree response to different irrigation strategies. 32 plots $72 m^2$.
14 NWAFU	1-Ansai	1973	Measurement of water balance, runoff, sediment losses, nutrient cycle and yield in different field crops and apples. Two hundred 200 plots, with sizes from 10 to 400 m^2.
	2- Zhifanggou	1973	Measurement of erosion process and runoff and sediment losses from the catchment. Land use in the catchment include forest, grassland and crops (corn, potato, millet, soybean, apples). One 82700 ha experimental watershed.
19 ULANC	1- Newby Beck	2010	Measurement of runoff, water quality and hydrological variables at the catchment outlet and further monitoring embedded catchments to determine the impact of diffuse pollution control measures implemented in the agricultural areas (cereals, and potatoes) within the catchment, which are wheat based rotations. One 12500 ha and three 1000 ha catchments.
	2- Whinton hill	2010	Measurement of runoff, water quality and hydrological variables at the catchment outlet to determine the impact of diffuse pollution control measures implemented in the agricultural areas within the catchment, which are cereals and a root crop, usually potatoes. One 10500 ha catchment.

Table 3
Structure of open data platform with examples for contents.

Database level	Data type	Contents	Comment
Site	Meta data	Location (long., lat.), country, area, climate type, soil type, slope, elevation, orientation	Characterization of experimental site
Treatment	Data set description	Treatment name, related plot, management type, trial period	Characterization of experimental type
Data set	Data group classes	Data files for crop, management, runoff, soil characteristics, water flux, weather	Data set consisting of different data files
Data file	Measured values	Array of measured values (and units) such as sediment yield, runoff, saturated hydraulic conductivity	Detailed description in guidelines on database webpage

water redistribution processes and feedback responses to crop spatial variability, in aiming to assist the development of precision farming, e.g. decision making regarding variable rate application of irrigation water and fertilizer.

Point-based models can evolve multi-dimensionality by integrating some of the hydrological modeling approaches. However, can this be achieved without making calibration and parameterization too complex? Already, point-based tools may be spatially interpolated for analysis at field scale without introducing further complexity. However, leaving water redistribution flows out of the models masks and/or smooths actual spatial heterogeneity in crop yield response that precision decision making aims to deal with. Our ongoing work in SHui aims at answering which might be the best strategy to model spatial heterogeneity in crop simulation models.

Another part of the project seeks to integrate hydrological modeling at both field and catchment scales. After selecting suitable models for individual scales as standards, these will be calibrated and validated using data from experimental plots and catchments. The models will improve understanding of hydrological processes within the soil system at various scales, to assist in implementing better algorithms in crop models that describe processes in the soil-plant-water system. Secondly, models of both detailed and larger scales will be used within the project to design and assess methods to resist climatic effects such as temporally irregular distribution of precipitation and resulting droughts. Detailed models, e.g. HYDRUS 1D and HYDRUS 2D (Šimunek et al., 2008), will mainly be utilized to describe how soil properties are changed by management practices, and to include horizontal processes in plot scale, e.g. subsurface lateral flow. The detailed process based model will improve AquaCrop's description of water flow and retention within the soil profile. Catchment scale models will be calibrated using experimental data and then used to design and validate optimum management practices (such as changes in crop rotation, land-use changes and/or implementation of different soil management techniques) to optimize water regime and to increase water storage capacity.

The models selected for application are physically based, continuous numerical models HYDRUS 1D and HYDRUS 2D/3D for detailed scale and MIKE SHE (Abott et al., 1986) and SWAT (SWAT, 2019) for catchment scale. MIKE SHE is an integrated model of groundwater, surface water, recharge and evapotranspiration, while SWAT is widely used system for hydrological catchment modelling in large scale. Model WATEM/SEDEM (Van Oost, Govers, & Desmet, 2000) will be used to assess the effects of soil erosion, sediment transport and deposition as significant soil degradation process, in catchment scale. Table 4 provides a summary of the models envisioned to be used within SHui for this challenge. To cover conditions of both of Europe and China, experimental data from locations of various size and extensions in SHui sites (Fig. 1, Tables 1 and 2) are used for models calibration and validation.

These models will help validate and classify systems of practices, technologies and measures within individual regions to enhance agricultural sustainability under changing conditions. Close cooperation between the hydrological modelling teams and those providing and maintaining the database of experimental data is necessary. Furthermore, teams designing Best Management Practices (BMPs) within the landscape and providing Cost Benefit Analysis (CBA) to assess and validate their effectiveness will also need to cooperate with the modellers. Hydrological modelling will also be integrated with satellite imagery to extrapolate the effects of management practices to even larger scales.

2.3. Integrating crop and hydrologic modeling challenges at regional scale

Fine-scale agricultural processes, as discussed above, are conditioned by larger scale hydrometeorological processes and soil-water-vegetation interactions at the regional scale. SHui takes a multi-scale approach to model and observe soil water and vegetation growth. The regional land surface modeling system consists of AquaCrop (Raes, Steduto, Hsiao, & Fereres, 2009) driven by meteorological forcings extracted from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2, Gelaro et al., 2017). Soil parameters are derived from 1-km^2 soil texture information (De Lannoy, Koster, Reichle, Mahanama, & Liu, 2014) and vegetation parameters are extracted from European and Chinese databases using moderate to fine-resolution visible/infrared remote sensing data smaller than 1 km^2. AquaCrop will be set up to simulate at a 1-km^2 resolution over Europe and China, using efficient high performance parallel computing. Since AquaCrop is designed for point-scale applications, a number of

Table 4
Summary of simulation models and analysis tools used within SHui.

# Model	Description	Reference
AquaCrop	Crop simulation model for field scale.-	Steduto et al., (2009)
HYDRUS 1D, 2/3D	Hydrologic model for analysis of water flow and solute transport in porous media at plot scale.	Šimunek et al., (2008)
MIKE SHE	Hydrologic model for catchment scale.	Abott et al., (1986)
SWAT	Hydrologic and erosion model at large catchment scale.	SWAT (2019)
WATEM/SEDEM	Water, tillage erosion model at small catchment scale.	Van Oost et al., (2000)
CSLE	Chinese Soil Loss Equation erosion model for field scale.	Liu, Zhang, & Xie, 2002; Cheng et al., 2019
MMF	Morgan–Morgan–Finney. Erosion model for field or catchment scale.	Morgan, Morgan, and Finney (1984).

AquaCrop parameters need to be scaled to ensure realistic output at a gridded 1-km^2 resolution, for the complete European continent and China. The regional modeling will ultimately be performed with ensemble realizations to quantify the model uncertainty at each time and location. The latter will be achieved by perturbing select meteorological forcings, parameters and state variables. The regional simulations will be optimised based on common (ensemble) verification skill metrics computed relative to *in situ* and satellite observations (De Lannoy, Houser, Pauwels, & Verhoest, 2006), as well as relative to output from the Global Gridded Crop Model Comparison Initiative (Müller et al., 2017).

The current wealth of satellite data provides invaluable additional insight into soil-water-vegetation processes. Soil moisture and biomass estimates can be retrieved from coarse-scale passive and finer-scale active microwave missions, such as e.g. the Soil Moisture Ocean Salinity (SMOS), Soil Moisture Active Passive (SMAP), and the Sentinel-1 missions. Various vegetation indices and crop identification can also be obtained from finer-scale visible/infrared missions, such as Moderate-resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer (VIIRS) and Sentinel-2. These satellite-based retrieval products will be compared against AquaCrop simulations and *in situ* observations.

However, both satellite observations and AquaCrop simulations have limitations. Satellite observations are noisy, intermittent and especially optical data have multiple gaps due to cloud cover. While the AquaCrop model is temporally complete, it is a blunt representation of nature and suffers from inaccurate parameterization and meteorological input. By assimilating satellite information into AquaCrop, improved estimates of soil-water-vegetation processes are expected. More specifically, we aim at assimilating the satellite signal of radar backscatter from Sentinel-1 and radiometer brightness temperature from SMOS and SMAP into AquaCrop. To this end, ensemble soil moisture and vegetation simulations by AquaCrop will be propagated through a backscatter or radiative transfer model (i.e. observation operator, Reichle, De Lannoy, Forman, Draper, & Liu, 2014) to simulate what the satellite would observe. The difference between simulated and observed satellite signals is then used in an ensemble Kalman filter (De Lannoy et al., 2016) to correct the AquaCrop simulations. This will result in value added improved daily surface and root-zone soil moisture and vegetation estimates, along with their uncertainty estimates, across the entire Europe and China study area. These estimates will be tested using ground-truthed data assimilated from the SHui database described above. Using this modeling and assimilation system, SHui will provide information on the suitability of crop choices, water stress and yield estimates as well efficient irrigation measures to improve crop production.

2.4. Development of best management plans (BMPs) and digital tools

Advances in proximal and remote sensing have resulted in big data related to agricultural systems. However, there remains a gap between the availability of seemingly limitless continuous data regarding crops and their environment and actual data-driven decision making in agricultural field management. Existing agricultural decision support systems (AgriDSS) tend to be either very general, failing to represent the complex interactions among variables such as meteorological conditions, water, soil, topography, energy and crops, or extremely site specific. In addition, most existing systems are limited to scales of whole fields or farms without representing within-field spatial variability, and therefore result in management decisions that address fields as single homogenous units. Currently, existing tools require trained personnel to collect and handle data and to incorporate them into an AgriDSS, which introduces a major barrier to their implementation by small-scale farms (the majority in EU and China). To address these challenges, one of the main objectives of SHui is to build decision support algorithms (DSAs) based on crop-specific objective functions and convert these into practical and user-friendly decision support tools (DSTs) for mobile platforms. To develop these tools, data from three field trials, located in three different climatic regions in Israel, is being collected, processed and analyzed to recognize correlations between different variables, develop spatial sampling methods, define best management recommendations and build models for yield prediction and irrigation requirements.

The first field trial consists of a variable rate irrigation center pivot commercial field with a 200 m radius pivot (12.5 ha plot) of field crop (maize-cotton) rotation. The field, located in the arid Negev Desert, serves as a platform to develop and test a methodology for optimal spatial sampling based on initial collected environmental data and management zones (MZ) delineation. Collected data include proximal sensing (soil sampling and plant status) from 100 locations and remote sensing (UAV IR and multispectral imaging) that will be used to develop variable rate irrigation strategies and algorithms for decision making based on MZs. The second trial is a 2 ha commercial cabernet sauvignon vineyard located in the Judean Mountains south-west of Jerusalem. The vineyard is divided into 20 sub-units, each receiving variable rate deficit irrigation to overcome the effect of spatial variability in yield and increase profit by optimizing quality and yield. Data has been collected since 2017 and includes monitoring with remote sensing (satellite and UAV-based thermal imaging) and proximal sensing (soil water sensors and dendrometers) and *in situ* measurements of trunk size/growth, stem water potential, leaf area index and yield (quantity and quality). The third trial is a 2.6 ha commercial peach orchard located in the northern Upper Galilee region of Israel. The orchard, divided into 22 sub-units, is managed to overcome spatial variability via precision irrigation to increase profit by optimizing quality (fruit size) and yield. Data has been collected since 2017 and includes similar monitoring (remote and proximal sensing) to that of the vineyard. For both the vineyard and the peach orchard, data is analyzed to quantify in-field spatial variability. More information and visualization of the project's platforms is available as story maps at http://terravisionlab.com/eugene_kendel/. A multivariate model for partitioning the orchards into sub-field MZs has been developed based on a weighted multivariate spatial clustering model using machine learning algorithms (boosted regression trees) and spatial statistical methods (Ohana-Levy et al., 2019).

The case studies and method development in Israel will serve as a model for expansion into other regions and situations. Data from field trials in China and Europe will be incorporated in order to address their crop-specific objective functions and to develop best management recommendations and management maps that will serve as the basis for the development of additional site appropriate DSAs, DSTs and AgriDSSs.

2.5. Socio-economic analysis and policy recommendations

Managing water resources to maintain human and ecological needs remains a major global challenge. In agricultural production, improving water use efficiency is expected to play an increasingly important role to ensure global food and water security (Mekonnen & Hoekstra, 2016). Current water management practices often fail to reflect real water scarcity, causing social, economic and environmental consequences. The economics of water represents a key element of this research.

A meta-analysis can analyse different options to understand this challenge and outline a scheme of feasible solutions. Several hundred studies, applying a multitude of approaches, have considered the potential impacts of irrigation on food production. However, these studies have different foci from water crop modeling, evapotranspiration or reducing greenhouse gas emissions. A meta-analysis focused on irrigation and real farm management practices that can inform optimal water use in agriculture in China and Europe is envisaged within SHui.

A first analysis in the database of SCOPUS and WEB of Science for the period 2014 to June 2019 using at least one of these keywords: irrigation; sustainable water use; on-farm management of water; socio-economic aspects of water management; precision irrigation; economic efficiency of water use; farming water footprint, revealed 553 publications. Following an investigation of publication titles, 296 remained for an abstract analysis, revealing many experiments about important irrigation techniques (e.g. deficit irrigation, drip irrigation). Relatively few publications concentrated on the possibilities of saving water using on-field management practices like mulching of straw or plastic and modern soil conservation practices. As farmers are profit-minded and market-oriented, the socio-economic analysis of food production and assessments of the environmental performance of the developed best management practices, e.g. using water (Allan, 2011) and carbon (Wiedmann & Minx, 2008) footprints, are relevant.

Furthermore, an adapted cost-benefit analysis (CBA) that focuses on best on-farm water management strategies will be developed, thereby linking field experiments, results from the water modeling, and real farm-based management. Economic incentives often drive on-farm water management strategies, and adopting water-saving technologies is strongly related to farmers' economic decision-making (Levidow et al., 2014). An adapted CBA integrating both economic and environmental aspects can provide farmers with a comprehensive understanding of potential costs and benefits (Boardman, Greenberg, Vining, & Weimer, 2014, pp. 1–9) of new water management strategies. It also serves as a foundation for policymakers to form suitable incentive programs to promote the adaptation of those environment-friendly technologies. In this research, we will assess several water-saving technologies developed in the study regions, including alternate wetting and drying irrigation (Carrijo, Lundy, & Linquist, 2017), partial root-zone drying irrigation (Dodd, 2009), and water and fertilizer integration technology (Wang et al., 2018). Following a thorough evaluation of the current situation of farm management practices in the participating study regions, the aim is to develop an efficient strategic framework for regional and local allocation of soil and water resources.

2.6. Dissemination. Training of stakeholders from farmers to young scientists

While the rapid advance of technologies (mobile phones with internet access, web-based audio- and video-conferencing platforms, social media accounts) increases the range of dissemination opportunities to a large, interdisciplinary project such as SHui, a key element is to provide a range of engagement opportunities for both technophiles and technophobes alike. While pitching the research message at an appropriate level to the academic credentials of the audience will always be critical, understanding the most effective communication medium provides an additional layer of complexity requiring an understanding of target audience preferences. Consequently, the SHui project offers many different dissemination fora including the internet (https://www.shui-eu.org), social media, electronic and physical mailing lists, downloadable (from the project website) and physical brochures, press releases, webinars and more conventional face-to-face events ranging from stakeholder fora in the various catchments described below through to national and international disciplinary or multi-disciplinary conferences. These fora will inform a range of target audiences, including fellow academics and the project advisory board, individual farmers and large commercial enterprises, the food and agricultural industries, farmers' organizations (e.g. National Farmer's Union in the UK), catchment managers and the scientific or daily press. The frequency of communication depends largely on the progress of the project.

Multi-national projects such as SHui pose additional language challenges and opportunities. Funding to SHui from both the European Commission and the Chinese MOST immediately required dissemination in both Chinese and English, with SHui internet content being offered in both languages. Further translation of the project brochure (https://www.shui-eu.org/document-download/) into Spanish ensures some material is accessible in the three most commonly spoken languages worldwide. Nevertheless, farmers may often converse only in their local language, and physical brochures can provide a memory stimulus after an initial stakeholder meeting, requiring additional translation by consortium members. Social media again requires different platforms (Twitter throughout much of the world, Weibo in China) even if the information content is identical. Internet-based information delivery easily facilitates monitoring the level of interest (e.g. number of website visitors, followers on social media) even if the effectiveness of knowledge transfer cannot be known.

The expertise of more senior researchers can be employed to train early career researchers (ECRs) within projects such as SHui, allowing diverse opportunities beyond those conventionally offered by more generic training in project management and communication skills. Many scientists discuss the importance of mentoring in developing individual careers and disciplinary knowledge (Brevik, 2010). Within a large multi-disciplinary project such as SHui, such training is essential to ensure that ECRs, typically recruited because of their skills in a specific discipline, develop a common technical language to facilitate interactions across partners and workpackages. While the emergence of "undisciplinary" scholars within more holistic areas such as sustainability science (Haider et al., 2018) offers alternative learning journeys, the need for integration within large projects remains. Aligning 1–2 day training workshops with SHui project meetings provides a time- and resource-efficient means to offer specialist training in specific areas. For example, the first SHui annual meeting in Fuzhou, China hosted a computer-based workshop in crop (AquaCrop) and hydrological (Hydrus, SWAT) modelling to give all participants an *in silico* experience of the learning opportunities, and time for the trainers to reflect on the success (or otherwise) of their delivery. While such face-to-face teaching allows immediate interactions to resolve uncertainties, they are restricted to those physically present (ie workshop participants) and are ephemeral, while webinars increase the geographical reach and temporal longevity of the training. Thus both workshops and webinars are envisaged within SHui.

Engaging with farmers is essential if the scientific and socio-economic lessons learned from SHui are to affect practices, thereby decreasing the environmental burden of farming. Translating agronomic and/or soil science data into monetary values can influence business (farmer) practice. However, personal interactions between farmers and extension specialists/scientists are usually needed to successfully ensure effective research translation, particularly when changes in management practices are proposed. This is especially necessary when farmer surveys establish considerable resistance to change when offered different irrigation practices in a theoretical choice experiment, even within a context of inadequate irrigation supply (Howell, Shrestha, & Dodd, 2015). When appropriately timed in the farming calendar, open days and stakeholder events provide opportunities for formal advisor/

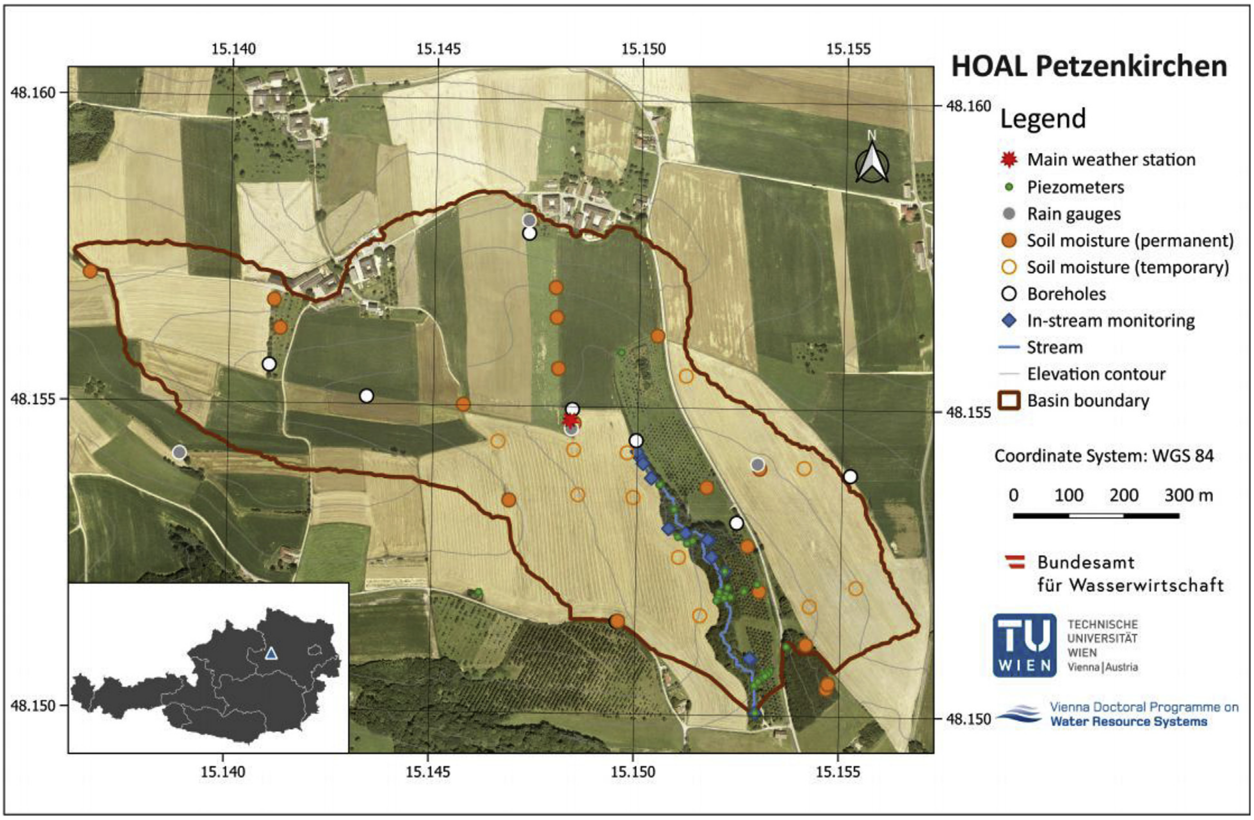

Fig. 3. Overview of current equipment and measurements at HOAL Petzenkirchen, Austria.

advisee and informal peer-to-peer learning, even if the latter may be inhibited by the commercial realities of competitive advantage. Nevertheless, such events provide a vehicle for SHui researchers to deliver on the impact agenda envisaged by the funders, and are essential for raising community awareness of the research agenda elaborated in this article.

3. Selected examples of long-term hydrological experiments and objectives

Below there is a description of long-term experiments integrated in SHui, which were started many years before the project. SHui's role is to integrate these projects into a common platform to explore synergies among them and in the model analysis as well as to provide some support to them during the duration of the project.

3.1. *HOAL: an intensively monitored catchment*

One catchment with long-term monitoring that SHui will make use of is the 'Seitengraben catchment' at Petzenkirchen, Austria, known as Hydrological Open Air Laboratory (HOAL) Petzenkirchen. The HOAL Petzenkirchen is located at 48°9′N, 15°9′E in the pre-alpine forelands of Austria. The catchment area extends to a size of 66 ha with a mean slope of 8%. The underlying geology for the HOAL Petzenkirchen are Tertiary sediments and fractured siltstone. The dominant soil types are Cambisols and Planosols with medium to poor infiltration capacities. Gleysols occur close to a stream. At present, 87% of the catchment area is arable land, 5% is used as pasture, 6% is forested and 2% is paved. The crops are mainly winter cereals, maize and rape. The climate is humid with a mean annual temperature of 9.5 °C and a mean annual precipitation of 823 mm·yr^{-1} (1990 to 2014). Mean annual flow at the catchment outlet is 195 mm·yr^{-1} (1990–2014). Fig. 3 provides an overview about the current sensor installations in the HOAL Petzenkirchen. More background information may be found in Blöschl et al. (2016). A webpage provides information on current research activities, news and recent publications (https://hoal.hydrology.at/index.php?id=2).

Observations in this catchment started in 1945 and are ongoing. Obviously, the number, spatial and temporal resolution and the type of measurements have changed substantially over the years. A first measurement period between 1945 and 1955 focused on measuring total stream flow (paper strip flow recorder), climatic parameters such as rainfall intensity (paper strip ombrograph), wind speed and temperature as well as sediment concentration (daily samples taken manually). Detailed descriptions of land use, land management and crop distribution were also recorded. A second campaign of observations started in 1991. Since then, the number and quality of monitored parameters is continuously increasing. In 2009, a cooperation agreement between the Federal Agency for Water Management and the Technical University Vienna was signed with the purpose to initiate HOAL Petzenkirchen. This led to the current evolution of catchment instalments and generated data.

Within the Shui project, HOAL Petzenkirchen will contribute to several activities across different workpackages. Current activities include implementing the catchment model SWAT (SWAT, 2019) and evaluating how and to what extent large scale catchment models can be applied at the small catchment scale in cooperation with BOKU. In cooperation with CVUT, the MIKE SHE model (Abbott, Bathurst, Cunge, O'Connell, & Rasmussen, 1986) is being implemented in the HOAL Petzenkirchen by simulating effects of the spatial variability of topsoil water content within the catchment, and in cooperation with BFU the effects of climate change

Table 5
Basic parameters of experimental catchments, used for models calibration and validation within SHui project.

Country	Area (km^2)	Duration (years)	Locality	Management type
UK	125 (3 embedded 10 km^2 each)	9	Newby Beck	cereal based crop rotation
UK	105	9	Whinton Hill	cereal based crop rotation
Czech Republic	9	30	Bykovice	cereal based crop rotation
Austria	0.66	50	Petzenkirchen	cereal based crop rotation
Czech Republic	0.5	6	Nucice	cereal based crop rotation
Spain	0.08	5	Cordoba	Olive tree
China	827	47	Zhiffanggou	mixed land use catchment with orchards and cereal based crop rotation
China	162	15	Zhangjiachong	mixed land use catchment with orchards and cereal based crop rotation

and long-term land use change sediment loads and concentrations are been investigated. An on-going PhD thesis is developing methodology to study the effects of management directions (across slope *versus* along slope cultivation) on soil loss and surface runoff.

3.2. Long-term runoff plot experiments in agricultural areas

Data from long-term experiments can help support decision making, with longer data series providing more reliable data sets. In addition, the data can be used to develop, calibrate and validate simulation models. Unfortunately, long-term field experiments (>15 years) are very rare because they are labor intensive and expensive (Miao, Stewart, & Zhang, 2011). Long-term experiments vary in goal and duration of the study, size of the field plots, and soil, climatic and management conditions (e.g. Richter, Hofmockel, Callaham, Powlson, & Smith, 2007).

In 1994, a field study started at three sites in eastern Austria (Mistelbach, Pixendorf and Pyhra) to investigate the impacts of different soil tillage systems on soil erosion, surface runoff, nutrient and pesticide losses as well as effects on crop yield. The same treatments are investigated at all sites: (1) conventional tillage system with autumn ploughing (CT), (2) mulch tillage with cover crops during winter (MT) and (3) no-till with cover crops during winter (NT). The study design is a randomized block and each treatment was replicated twice. The experimental plots are 6 m wide and, depending on site conditions, between 40 and 80 m long. The study design consists of 3–4 m wide and 15 m long runoff plots for each management variation (Klik and Strohmeier, 2011) bordered by 20 cm high stainless steel metal sheets. At the lower end of the plot, surface runoff and soil loss are collected in a trough and then diverted by a 100-mm PVC pipe to a tipping bucket type Automated Erosion Wheel (AEW, Klik et al., 2004). Soil-water-suspension is divided by an adapted multi-tube divisor taking 3.3% of the sample into a 60 L collection tank.

Runoff and soil loss are measured on an event or weekly basis throughout the growing season (April to October). Amount of runoff and soil loss are determined as well as nutrient (nitrogen, phosphorus) contents and sometimes, depending on research objectives, also pesticide concentrations in water and sediment samples are also analyzed. Continuous measurements of soil water content in the root zone are available at the Mistelbach site in 2002 and 2003. In several years, soil aggregate stability was also determined. Crop yields are measured for all treatments. At each site an automatic weather station registers precipitation and air temperature. Altogether, 44 plot years of cereal-based rotations are available for the three sites with 20 years of measurement in Mistelbach, 14 years in Pixendorf and 10 years in Pyhra with overall 223 data sets.

SHui also encompasses long-term plot experiments in tree crops, such as in a commercial olive orchard under deficit irrigation located in Benacazon, Spain (*37° 20′ 24′ N, W, 6° 13′ 1″*).This comprises six runoff plots (480 m^2 each) on an 11% slope, measuring runoff and soil losses under different soil management strategies. One management system is bare soil based on the traditional tillage in the area (2–3 cultivator passes a year) and temporary cover crops which are seeded in early autumn and chemically or mechanically mowed in mid spring to prevent competition for soil water. The kind of cover crops tested in the area have varied, often annual grasses (e.g. *Lolium rigidum*, *Bromus rubens*) or mixes of several species of different families to enhance biodiversity (Gómez et al., 2018). Self-seeding of these covers is intended but experience suggests re-seeding is needed every 3–4 years. The experiment aims to measure the effect of soil management on runoff and sediment losses, using a system of collection tanks connected through flow splitters which can measure small and large storm events. Nutrient and organic carbon losses have also been determined during some periods (e.g. Gómez et al., 2017) along with biodiversity impacts of different kinds of cover crops. Since 2019, two plots (one with cover crop and another with bare soil) are monitored to measure soil water content at different depths in the alleys and in the tree lanes.

3.3. Catchment hydrology

As mentioned in the previous sections, a major aim of the SHui project is the search for relationships between plot and catchment scales to bridge hydrology and land-use. Cropping is an important type of land use. The research and development will be focused on the relationship between individual crops, their seasonal development, management practices used, soil preparation techniques, fertilization and organic matters management, and how these interact with the water regime of the soil profile and the catchment response. There are data from long-term experiments available, describing rainfall-runoff processes at mostly plot to field experimental sites (see section 2.1) and similar long term experimental data (some of them from the same sites) in plot to field scale, describing relations between hydrological balance and crop yield (see section 2.1). While particular detailed processes are well documented, the effect of spatial distribution of soils, the catchment morphology and its influence over concentrated flow, including interaction of surface and subsurface hydrological processes differs from the plot/field scale to the catchment scale.

There are also long-term rainfall-runoff and hydrological balance data sets from small to medium catchments within the project teams from the Czech Republic, Austria, Spain, UK and several localities in central and northern China. These datasets include information about crops and crop rotations and utilized technologies. The effects of soil, land, and crop management on water quality will also be studied at the catchment scale to understand hydrological flows.

The data and catchment scale models will be used to study the potential of crop management, concerning optimum timing, soil management, rotation and spatial distribution on retention capacity and hydrological response and behavior of agricultural catchments. We will study the effect of changes in soil properties, conditioned by crop yields, temporal development of individual crops and mainly their spatial distribution over the catchment on hydrological cycle. Several data sets, summarized in Table 5, will be utilized. SHui welcomes collaboration with partners bringing additional experiments and agreeable to joint specific actions such as workshops or studies on model comparison across catchments.

3.4. Long-term water balance experiments and crop productivity

In arid and semi-arid regions, which are often characterized by competition for water resources, restriction on water for agriculture is fostering the search of alternative water resources, such as the reuse of reclaimed water (RW), and water-saving techniques, such as regulated deficit irrigation (RDI) strategies to cope with forecasted food production requirements (Pedrero, Mounzer, Alarcón, Bayona, & Nicolás, 2013). RDI may be defined as supplying less water (than crop evapotranspirational needs) at specific times in the cropping cycle when the crop is less sensitive to withholding water. Two long-term experiments carried out by the CEBAS-CSIC team offer two scenarios: 1) Intensive cultivation of citrus in coastal areas and 2) extensive grape production for wine making in inland areas of Spain. Existing data from these experiments provide opportunities to assess the validity of new AquaCrop modelling scenarios for perennial crops, the use of localized irrigation and the accumulation of soil salinity.

3.4.1. Scenario 1. citrus trees

Experiments in the Murcia Region (Spain) studied the physiological and agronomic effects of irrigating a young commercial grapefruit (*Citrus paradisi* cv Star Ruby grafted on *Citrus macrophylla* rootstock) orchard with two water sources (saline RW *versus* conventional water) in factorial combination with two irrigation strategies (conventional irrigation *versus* an RDI strategy). Water transferred from an irrigation canal (TW; electrical conductivity, EC ~ 1.3 dS m^{-1}) and RW from a wastewater treatment plant (EC~3.0 dS m^{-1}) were compared, with control irrigation supplying 100% of the crop evapotranspiration (ETc) while the RDI treatment was irrigated at 50% of ETc during the 2nd stage of fruit growth (Pedrero et al., 2015). Although the RDI treatment decreased annual irrigation volume by 13.2%, soil salinity substantially increased in summer in the RDI treatment due to a greater water demand. While these treatments did not negatively affect vegetative growth, yield and fruit quality, trial duration (2008–2010) was short in relation to the commercial life of a citrus grove, requiring further research over a longer term. Farmer decision-making on the long-term economic viability of different irrigation strategies in perennial crops is likely to be more conservative than in annual crops, highlighting the need for a longer-term socio-economic analysis than is possible within projects of SHui's duration (2018–2021).

To consider these possible long-term effects of salinity on soil and crop production, a new experiment was evaluated during six consecutive seasons (2008–2013) in the Murcia region (Nicolás et al., 2016) within a commercial mandarin (Citrus clementina cv. Orogrande) orchard. After applying similar water sources as above, RW decreased vegetative growth especially from the third season, with reductions of crop fruit load that were more prominent since 2011, significantly affecting the yield and water productivity. Suitable management practices (e.g. applying a leaching fraction) will be implemented in SHui to ensure the sustainability of soils and mandarin yields subjected to long-term use of these non-conventional water resources.

3.4.2. Scenario 2. grapevines

Research initiated in 2012 continues within SHui, to explore the effects of applying two different strategies: a) RDI in comparison with rainfed conditions and a full irrigation control and b) comparing water high in salts with rainwater of standard quality.

a) Sustained Deficit Irrigation (SDI) experiment.

Within a commercial vineyard (*Vitis vinifera* L. cv. Bobal grafted onto 161-49C Couderc rootstock) located near Requena, Valencia, Spain, three irrigation treatments with good quality water (EC of 1.1 dS m^{-1}) were initiated in 2012:

- Rainfed, receiving only rainfall water
- SDI, where irrigation replaced only 35% ETc during the whole year, with an average water application of only 82 mm
- Control where water is applied at 100% ETc resulting in irrigation volume of 278 mm

During the first three seasons (2012–2014), SDI was the preferred strategy to substantially improve yield (by 49%) compared to the rainfed regime, thereby significantly increasing water use efficiency (calculated considering both precipitation and irrigation). However, yield increments at 100% ETc were offset by detrimental effects that full irrigation had on grape composition. In this case, 8 years of these irrigation treatments produced similar results to the first three seasons of water application, suggesting cost benefit analyses of different deficit irrigation treatments over 3 years (e.g. Garcia Garcia, Martinez-Cutillas, & Romero, 2012) may provide useful results to inform farmer choice.

b) Irrigation with water high in salts

Within a commercial vineyard (*Vitis vinifera* L. cv. Monastrell grafted onto SO4 rootstock rootstock) located in D.O. Jumilla (SE Spain), four irrigation treatments were initiated in 2016:

- Rainfed, receiving only rainfall water
- SDI, irrigating to only 35% ETc, with water of moderate EC (1.8 dSm^{-1})
- SDI, irrigating to only 35% ETc, with sulphate-laden water ($MgSO_4$ and Na_2SO_4) of high EC (5 dSm^{-1})
- SDI, irrigating to only 35% ETc, with chloride-laden water (NaCl) of high EC (5 dSm^{-1})

After 3 consecutive irrigation seasons, the standard water quality SDI treatment increased yield by 33% compared to the rainfed treatment, slightly more so than the sulphate- and chloride-laden water treatments. Nevertheless, the rainfed regime increased (all years) grape anthocyanin concentration, wine color intensity and the overall wine consumer acceptance evaluated by a tasting panel, indicating the importance of quality testing when evaluating different irrigation treatments. These treatments will be extended in SHui to corroborate if the long-term application of high salinity water impairs grapevine crop performance (as in citrus). Moreover, data from this experiment will be utilized in developing the fruit tree crop model and in validating and improving AquaCrop (Section 2.2).

4. Conclusions

Sustainably increasing food production requires that use of soil and water resources are optimised across scales (from plot to field and catchment and beyond this to regional level) for major cropping systems. This requires coordinated projects that transcend disciplines, with data from long-term experiments available in well-curated and coordinated research platforms, thereby providing a baseline to evaluate scientific and technical breakthroughs suitable to transfer knowledge from academia to farmers, companies, government agencies, NGO's and policy makers. Among the most relevant scientific challenges identified within SHui are:

1 Closing the gap between hydrological and crop models to explore whether determining spatial variability of soil properties can allow more efficient management of crops at field and small catchment scales. Some avenues to address this are: i) reinforcing the soil water component of widely used crop models (e.g. AquaCrop) by combining their predictions with more physically based models such as Hydrus 1D and 2D; ii) developing procedures to upscale the effect of changing crops use and management at watershed scale combining simulations with point-based crop models and hydrological models; iii) exploring the implications of using fully coupled 3D hydrological and crop models at field scale, particularly to determine if the cost of increased management complexity is compensated by minimal spatial variability of crop yields within different areas of a field; iv) coupling crop models and soil moisture satellite data to make assessments at large regional scales
2 Articulating best management practices to characterize spatial variability of soil water related properties for different soil and environmental conditions and couple them with decisions support systems (DSS) to simplify on-farm decision-making. Developing these DSS will require identifying specific farming situations with robust and easy to interpret (by stakeholders) algorithms.
3 Developing robust cost benefit analysis to translate the effects of changing crop management into meaningful variables, such as impact of management strategies for expected yields, profitability, water savings or reduction of soil losses, for stakeholders at different levels (from farmers to senior policy makers), to assist decision making across different scales.
4 Developing and testing an integrated curriculum for optimizing soil and water use in agricultural systems across different disciplines and stakeholders, particularly for the new generation of farmers, technicians and scientists.

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