Online Parcel-scale Irrigation Management in Romania: Spatio-Temporal Soil Moisture Modeling Using SPHY

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Preface

The Netherlands' "Partners for Water" initiative has the objective to support the Dutch water sector to capitalize on its technologies and expertise internationally, while simultaneously ensure that Dutch technologies and knowledge contribute to solving world water challenges.

A call for proposal was announced by "Partners for Water" 2013. A consortium of three Netherlands' partners developed a proposal on request of five beneficiaries in Romania, under the name "OPI Romania – Online Irrigation Management at Field Scale". The project was granted on 23-Apr-2013 and runs from April 2013 to June 2015.

The contract number is PVWS13007.

The project partners are:

- Beneficiaries in Romania:
  - National Administration Apele Romane, Banat River Basin Administration.
  - ANIF - National Agency for Land Development
  - OPSA Timisoara
  - Emiliana West Rom Ltd
  - Bardeau
- Project implementation:
  - Crop-R, Groningen, Netherlands (lead)
  - FutureWater, Wageningen, Netherlands
  - Dacom, Emmen, Netherlands
  - KnowH2O,Berg en Dal, Netherlands

Project partners acknowledge the financial support of Partners for Water in implementing the project.

1 Introduction

1.1 General background and objectives of the project

The agricultural sector is the largest human-induced water user in most countries. The Food and Agricultural Organization (FAO) of the United Nations reports that around 70% of global water use is withdrawn with an agricultural purpose. With a growing world population, global water demand for the production of food, fiber and energy crops is rapidly increasing. In many areas, climate change is expected to lead to a higher frequency and magnitude of extreme events such as droughts and floods. The agricultural sector could play a key role in saving water by achieving “more crop per drop”.

A product that is capable of quantifying soil moisture in the root zone and actual evapotranspiration could improve sustainability and productivity of water management by governments, water managers and farmers. Under drought conditions, for example, a water boards could improve their policies on water distribution, and farmers could identify locations and points in time where irrigation is urgently needed.

The current project OPI Romania, funded by Partners for Water (The Netherlands), proposes an integrated approach to develop a product that could support:

- optimal irrigation management,
- effective water use,
- higher crop production, and
- an investment for better cost/benefit ratio.

The product was applied in a test case for a large farm in the Banat region of Western Romania, Emiliana West Rom near the town of Sannicolau Mare.

1.2 Approach

Effective water use leads to higher crop yield, and optimal crop transpiration is our target. Total evapotranspiration (ET) is the sum of:

- interception from leaves (partly for cooling),
- evaporation from soil (to be minimized), and
- transpiration of crops (production to be maximized!).

Intercepted rainfall and/or irrigation water by the crop leaves might evaporate (Ei). Potential evapotranspiration (ETp) is defined as the evapotransipiration of the crop under optimal growing conditions. Actual evapotranspiration (ETa) is the reduced amount due to stress (water, oxygen, and/or salt). The so-called evapotranspiration deficit (ETd) is defined as ETp minus ETa and is therefore an indicator of stress experienced by the crop. Heterogeneity in soil moisture can be caused by soil type, crop stage, crop type, field management, etc. Spatial and temporal control of soil water in the root zone is required to minimize the ET deficit and to maintain an optimal level of crop production.

To obtain insight in soil moisture conditions across space and time, an integrated approach is required that consists of field sensor measurements on soil moisture, remote sensing data on actual vegetation conditions, simulation of hydrological conditions by a spatial model, and an

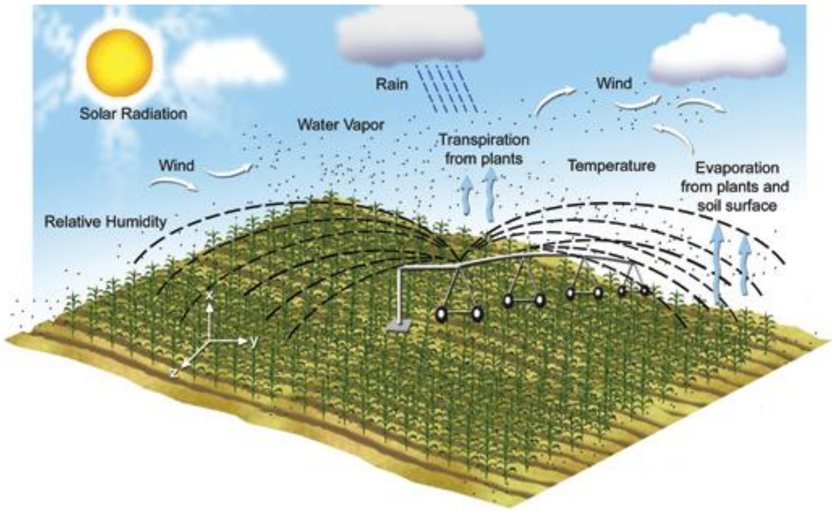

Figure 1 Factors affecting evapotranspiration, as a sum of evaporation of intercepted water and soil water and transpiration from plants.

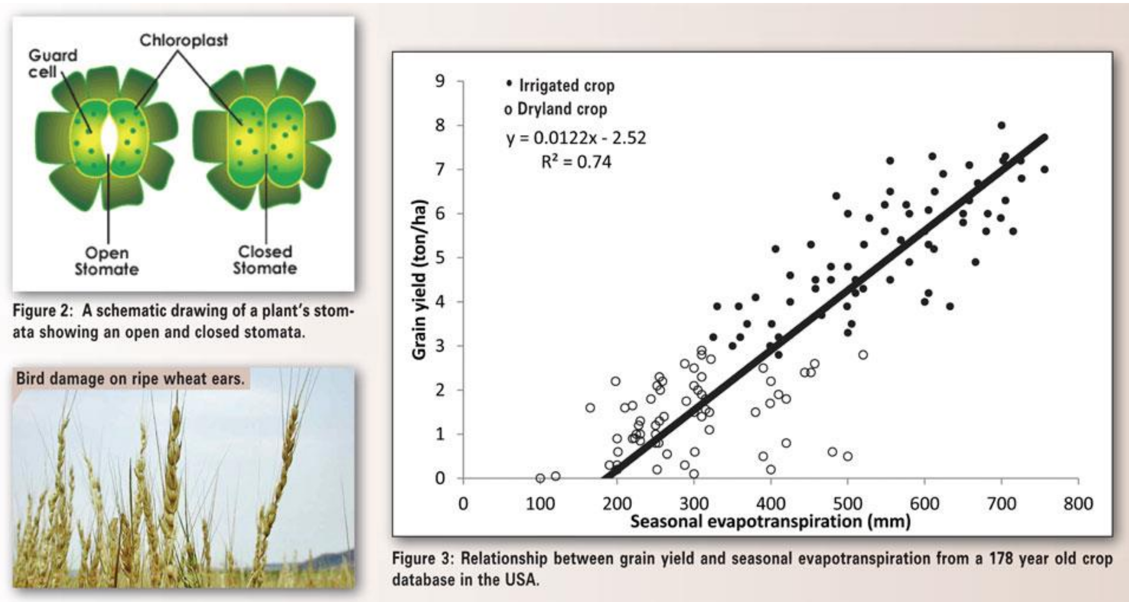

Figure 2 The relation between (evapo)transpiration and crop production.

online information portal that is regularly updated. A consortium of KnowH2O, FutureWater, Dacom and Crop-R was formed to cover all these aspects of the project.

1.3 Report outline

This report describes the hydrological modeling component of the project, which was performed based on field data and remote sensing information. Chapter 2 provides a description of the model that was applied, Chapter 3 describes the study area and the data that were used to feed the model, and Chapter 4 gives an overview of model outcomes and validation of the results.

2 SPHY hydrological model

2.1 General model description

Within the OPI Romania project, FutureWater is responsible for producing and integrating the spatial hydrological data that serve as the basis for irrigation advice, combined with field data on soil moisture in the root zone. These data are outputs of the Spatial Processes in HYdrology (SPHY) model that was built for the Emiliana farm in Western Romania.

The current version of the SPHY model (2.0) was recently scientifically published (Terink et al., 2015). The model was developed using the best components of existing and well-tested simulation models, and is developed with the explicit aim to simulate terrestrial hydrology at flexible scales under various land use and climate conditions. SPHY is a spatially distributed leaky bucket type of model, and is applied on a cell-by-cell basis. The model is written in the Python programming language using the PCRaster dynamic modelling framework. Compared to other hydrological models, that typically focus on the simulation of streamflow only, the SPHY model has several advantages: it (i) integrates most relevant hydrological processes, (ii) is setup modular, (iii) is easy adjustable and applicable, (iii) can easily be linked to remote sensing data, and (iv) can be applied for operational as well as strategic decision support. All these aspects are very relevant for an application in operational irrigation management.

The most relevant hydrological processes that are integrated in the SPHY model are rainfall–runoff processes, cryosphere processes, evapotranspiration processes, the simulation of dynamic vegetation cover, lake/reservoir outflow, and the simulation of root zone moisture contents. An overview of model processes, inputs and outputs is provided in Figure 3. Studies in which the SPHY model was successfully applied and tested range from (i) real-time soil moisture predictions to support irrigation management in lowland areas, to (ii) detailed climate change impact studies in snow and glacier-fed river basins, to (iii) operational flow forecasting in mountainous catchments.

SPHY is an open-source model and can therefore be freely downloaded from www.sphy-model.org, along with supporting documentation. A full description of the model principles and some applications can be found at (Terink et al., 2015).

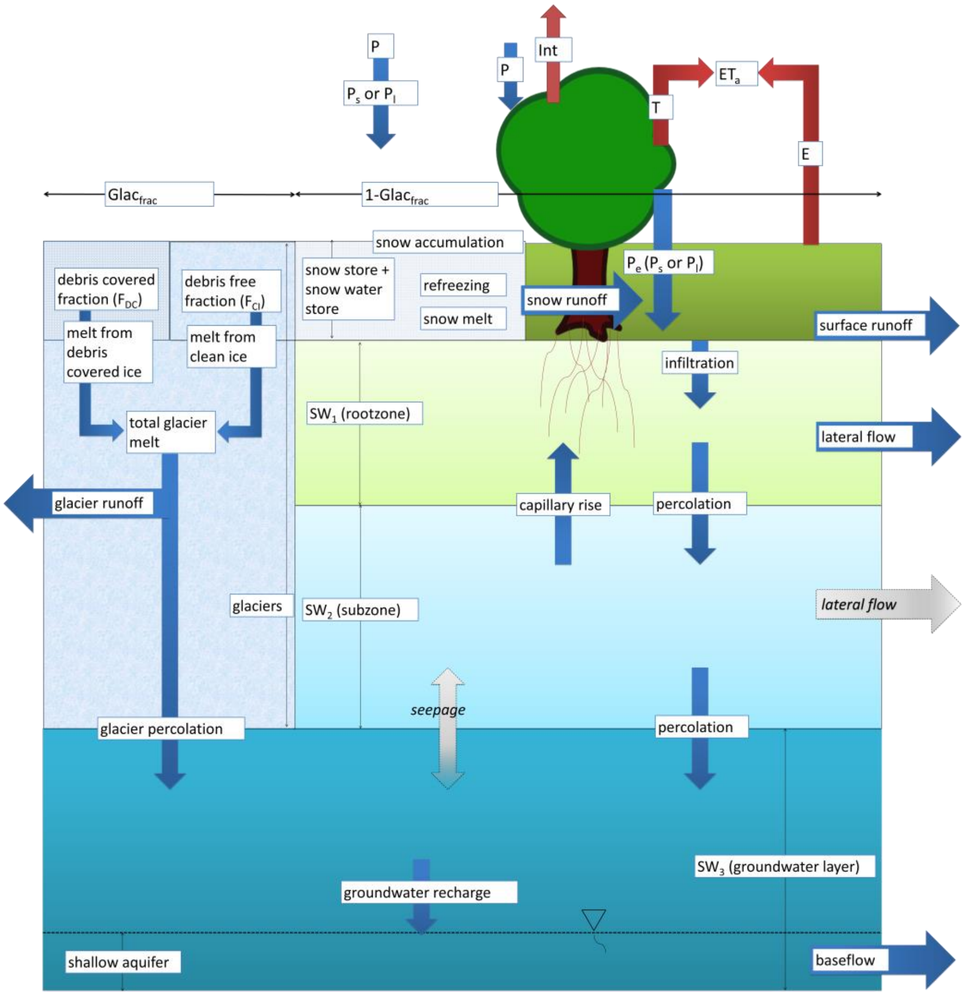

Figure 3 SPHY model and hydrological processes involved.

2.2 SPHY application in Romania

SPHY has been applied with the purpose of providing field-specific irrigation advice for the “Emiliana West Rom” farm in western Romania. A high spatial resolution is very relevant for supporting decisions on variable-rate irrigation. Therefore, the model has been set up using a 30 m spatial resolution, covering the 2013 and 2014 cropping seasons on a daily time step. For every day, spatial maps of root zone water content, ETa, ETdeficit, and rainfall interception Ei were produced.

In irrigation management applications, a model should be capable of simulating the soil moisture stress experienced by the crop due to insufficient soil moisture contents, which manifests itself by an evapotranspiration deficit (ETp > ETa). Field measurements of soil moisture and/or ETa are therefore desired for calibration purposes. Dacom capacitance soil moisture sensors were installed at several locations and crops at the farm. These sensors provide point information on soil water content used for calibration and validation of SPHY.

Figure 4 shows the model extent with the fields cultivated at the Emiliana farm at the Romanian-Serbian border and the location of Dacom soil moisture sensors.

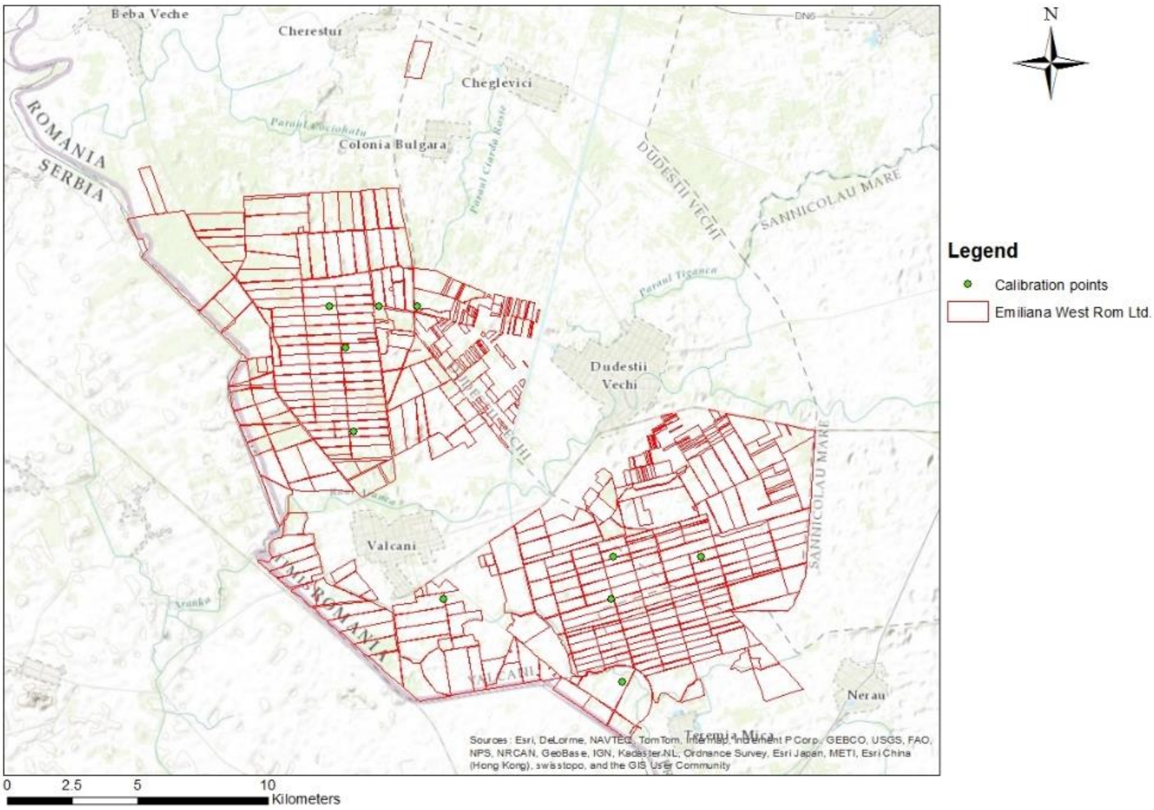

Figure 4 Location of Emiliana farm and the soil moisture sensors ("Calibration points")

3 Overview of project area and input data

3.1 General description of Emiliana farm

The Emiliana farm is located in the far West of Romania and comprises 380 individual fields. The total farm area is 13,000 ha. The irrigated area is expanding and currently covers around 4,000 ha. As illustrated by Figure 5, it is a reasonably flat area with all cultivated fields within 70 to 78 m. Elevation data was obtained from the EU-DEM dataset (EEA, 2014).

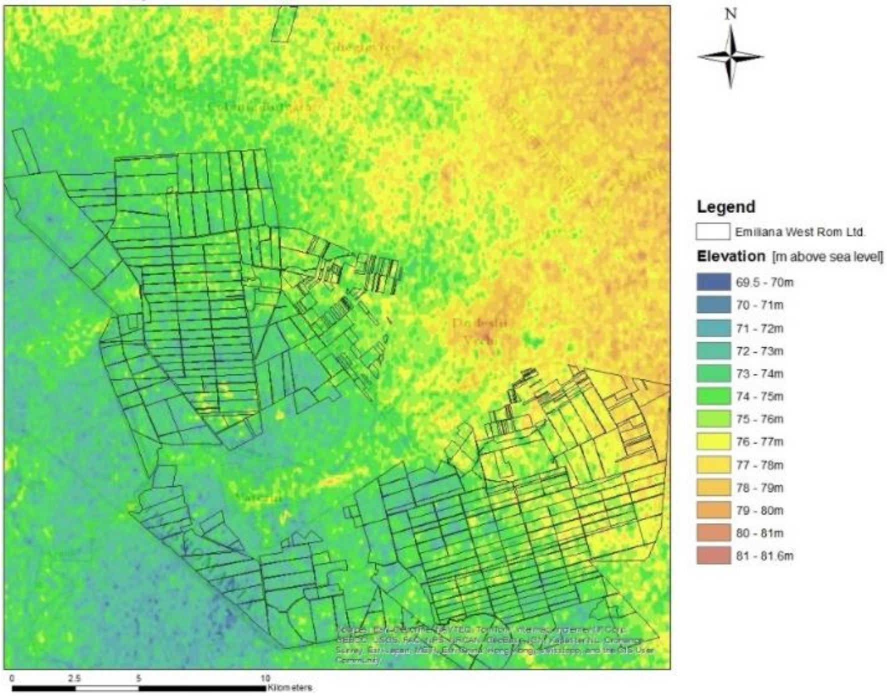

Figure 5 Elevation map of the Emiliana farm region

In the area, excess rainfall feeds the regional groundwater system. No surface or subsurface drainage is present.

3.2 Farm management

During the project, several visits were paid to the farm and discussions were held with the Emiliana agronomical department. Data were provided on their cropping patterns, and eleven different crops were identified. Figure 6 depicts the crop map for the 2013 summer growing season.

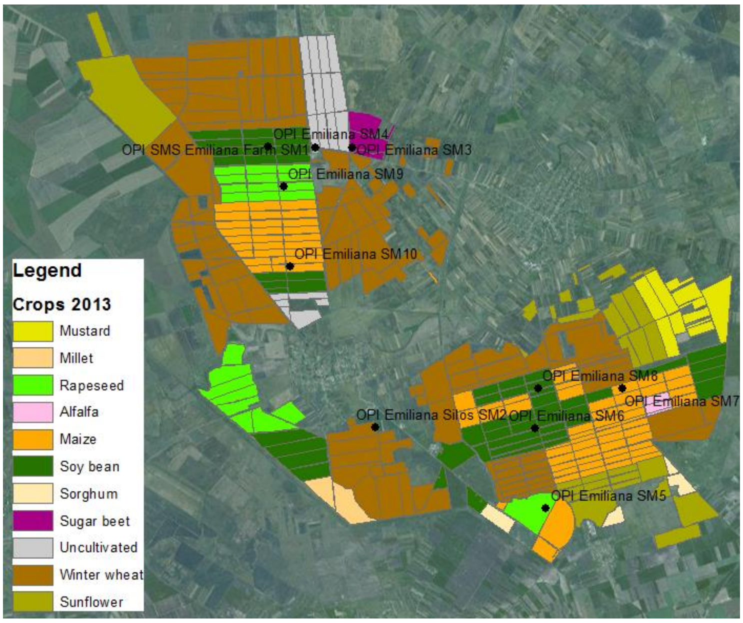

Figure 6 Crop map of Emiliana farm for the 2013 summer season

Satellite images are essential to incorporate actual crop conditions into a hydrological model. Optical satellite data from Landsat-8 (USGS, 2013) were used as input to the dynamic vegetation module of SPHY. The Normalized Difference Vegetation Index (NDVI) is a commonly used index of vegetation cover and health. NDVI maps with a 30 m resolution were calculated from the Landsat images, which are available for every 16 days. Figure 7 shows the NDVI map of a certain day (28 August 2014). It directly shows cropped and non-cropped fields, as well as intra-field variability of crop vigor. These NDVI maps are used by the model in the computation of ETp through a crop factor approach (see eg. Rafn et al 2008 and FAO Irrigation and Drainage Paper 56

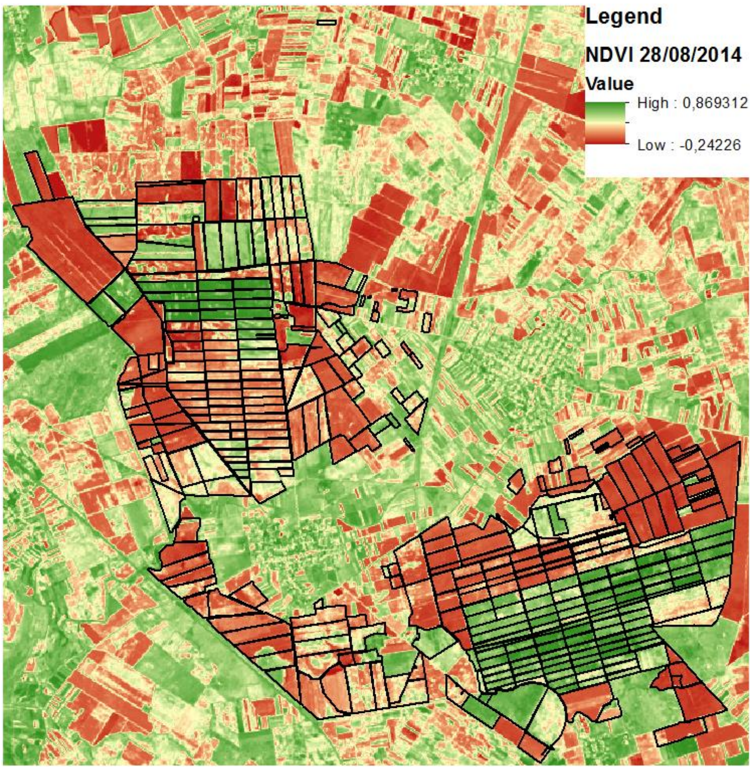

Figure 7 NDVI map of August 28, 2014

Irrigation practices were briefly discussed with Emiliana staff. Around 300 m3/ha of irrigation water is applied per hectare during an irrigation event (30 mm). It was reported that during the 2014 season, only one irrigation event was required. Irrigation water was applied halfway through May and no subsequent irrigation was deemed necessary. Therefore, a single irrigation amount of 30 mm was introduced for May 2014 in one of the SPHY runs. Overall, however, no detailed information on irrigation scheduling was available and the model runs were performed for a situation without irrigation.

Figure 8 gives an overview of all fields equipped for irrigation. During the 2013 and 2014 seasons, this was around 4,000 ha. It takes around 10 days to complete the irrigation of the total surface. Over the course of 2014/2015, irrigation equipment has been expanded to an additional area of 350 ha.

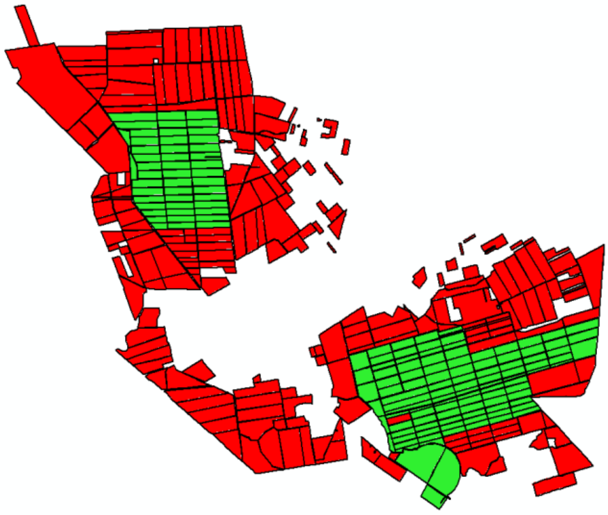

Figure 8 Fields equipped for irrigation (in green) and non-irrigated fields (in red)

3.3 Soil properties

A large part of the farm is known to consist typically of a heavy, dark, clayey soil type that becomes very solid when wetted. Emiliana owns a detailed soil map of the area but this map is reported to be old and unreliable. The staff base their decision making largely on their own knowledge of the local soils.

Therefore, soil properties for the SPHY model were derived from the Harmonized World Soil Database (Batjes et al., 2012), which for Romania contains data from the Soil Geographical Database for Europe (Lambert et al., 2003). Using the Van Genuchten equation (Van Genuchten, 1980), soil saturated water content, field capacity, and wilting point were determined for the HWSD classes occurring at the study site.

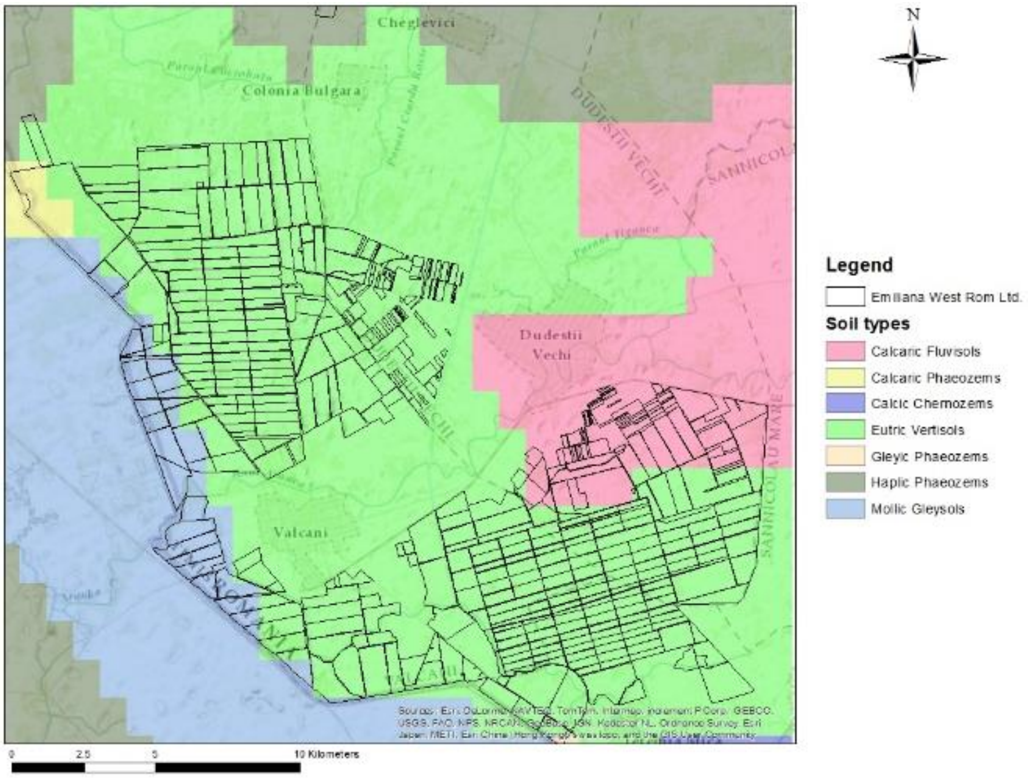

Figure 9 HWSD soil map of Emiliana farm

3.4 Climate

To force the SPHY model, information is needed on rainfall and reference crop evapotranspiration, the latter being computed based on daily maximum and minimum temperatures. The meteorological data were retrieved from the two weather stations installed within the farm area (Figure 10). Rainfall maps were based on spatial interpolation of the two local stations, supplemented by the nearby Szeged station for the period before August 2014. Air temperature inputs to the model are averages of the local weather stations.

Figure 10 Two weather stations installed at Emiliana farm

4 Model results

4.1 General

The SPHY-output consists of grid maps with hydrological variables such as ETa, groundwater recharge, and soil moisture content of the root zone. The SPHY model was run for the period July 1, 2012 until September 28, 2014 with daily time steps. Thus, 820 maps are produced per SPHY output variable. In addition, time series for certain point locations can be produced by SPHY, which is very useful for comparing measured and simulated soil moisture.

4.2 Simulated soil water content and ET-deficit

Figure 11 shows the simulated ET-deficit (ETd) plotted together with rain gauge data, averaged for all Dacom measurement locations. As the SPHY simulation does only incorporate one known moment of irrigation, this figure does illustrate the need for irrigation. It can be clearly seen that periods of drought in the area lead to reduced soil water uptake by the roots which is reflected in the ET deficit, and thus a suboptimal growth of the crop. This ETd is an indication of the water shortage that should be compensated by irrigation.

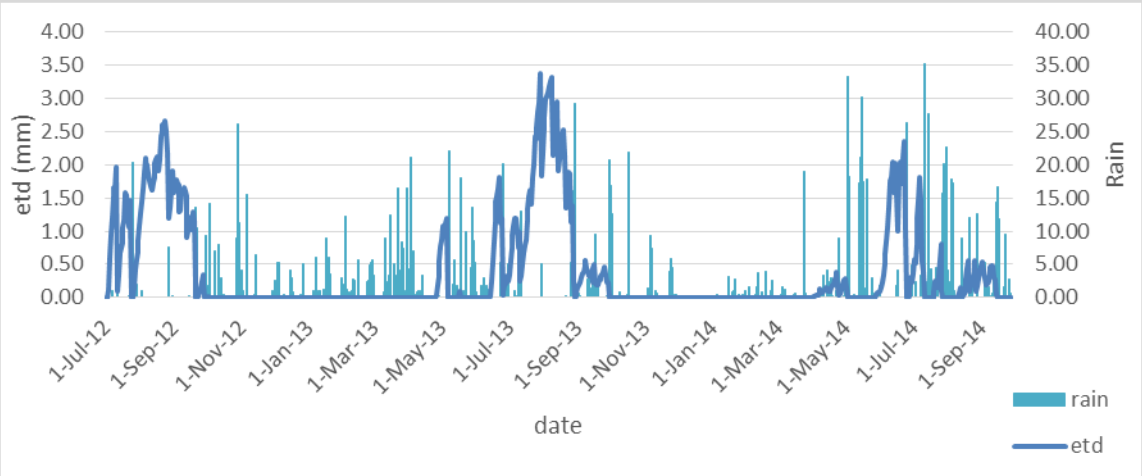

Figure 11 Average ET deficit at all Dacom soil moisture measurement locations

The spatial distribution of ETd at a certain day (July 2, 2014) is displayed in Figure 12. The crop experiences water stress (drought) in all locations where ETd exceeds 0 mm. Therefore, this maps shows the farmer exactly where irrigation is required, which is particularly in the red and yellow areas.

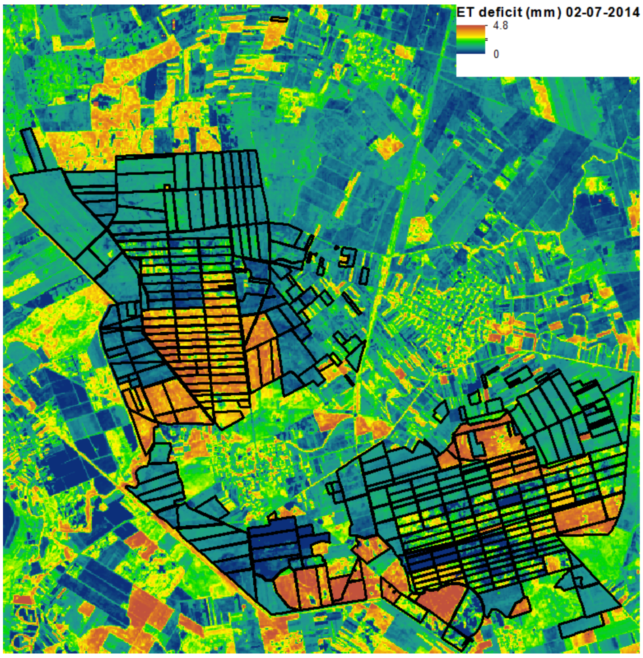

Figure 12 ET deficit on July 2, 2014, as simulated by SPHY

Figure 13 depicts spatial maps of NDVI, root zone water content and ETd as simulated by SPHY for a specific part of the farm, valid for day March 28, 2014. This provides insight in the relation between these different parameters. In general, an ETd is experienced on fields with a high NDVI and a low soil moisture content, although the effect of the latter parameter is also dependent on the type of soil. It should be noted that a static root zone of 400 mm was assumed in the SPHY simulations (see above). Therefore, the soil moisture values are valid for the upper 400 mm of the soil profile.

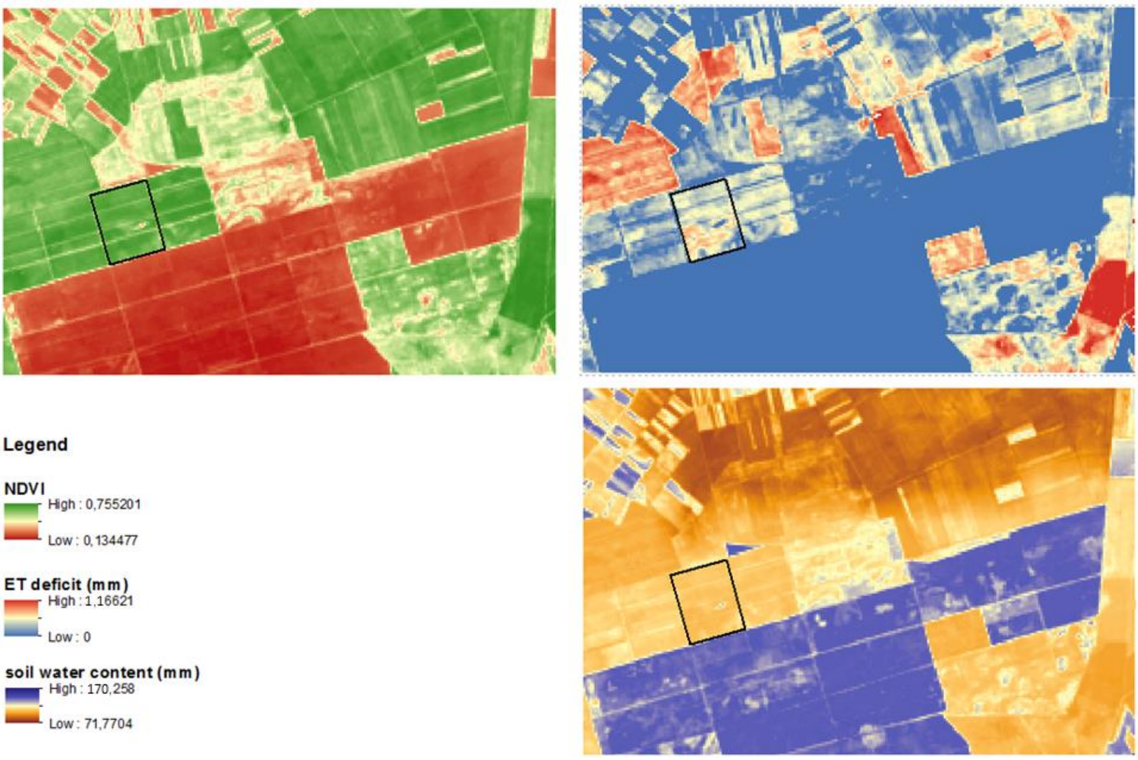

Figure 13 NDVI (Landsat-8), ETdeficit (SPHY), and root zone water content (SPHY) on March 28, 2014, showing a part of the Emiliana farm.

Calibration and validation of the SPHY model was foreseen by comparing simulations of soil moisture with soil moisture sensor measurements in the field. Model performance was evaluated for one of the longest time series of measured root zone soil moisture (Figure 14).. As can be observed, the temporal patterns as measured by the soil moisture sensor are well described by the SPHY simulation. Based on daily soil moisture values a Nash Sutcliffe model efficiency coefficient of 0.6 was found, indicating that the quality of prediction of the SPHY model is “good”, bordering “very good” (Foglia et al., 2009) for this location. It should be noted that soil moisture content is typically highly variable in space. A much higher correlation between point measurements and grid cell simulations of soil moisture may therefore not always be feasible (Bramer et al., 2013)

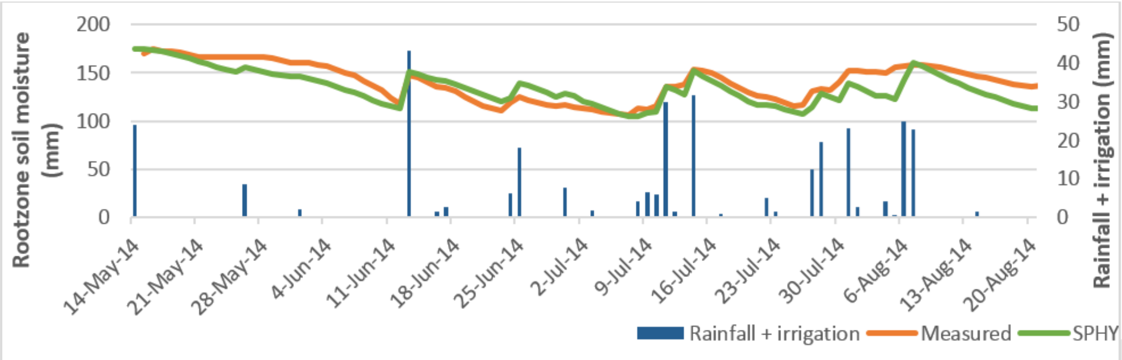

Figure 14 Daily soil moisture as measured and modelled in one of the Emiliana soy bean fields

5 Concluding remarks and recommendations

- From this demonstration project it can be concluded that SPHY is a suitable tool for providing insight in spatial and temporal variability of root zone soil moisture and evapotranspiration deficit. This is the basis for optimal irrigation water management.

- An integrated approach of field measurements, SPHY modeling based on remote sensing and a web-based platform is required for covering the full information chain towards enhanced irrigation decision support.

- A longer period of soil moisture sensor measurements in the future is expected to improve model calibration and validation opportunities. Also, calibration on ET field measurements may further enhance the performance of SPHY in soil moisture simulation and irrigation decision support, although such data is often not available as ETa is a very complex parameter to assess (Samain et al., 2012).

- By running the model on an operational basis, forced by weather forecasts, the developed irrigation decision support system could provide spatial irrigation advice on a daily basis for the forthcoming five days. This allows the farmer to mitigate expected water shortages and optimize crop production at the field scale.

6 References

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