Online parcel oriented irrigation advice Romania

Optimization of agricultural water resource management by using the SPHY model

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Preface

This report is my Bachelor thesis, which I have written during my internship at FutureWater in Wageningen, The Netherlands. It is part of my graduation of the study Land and Water management at Van Hall Larenstein University of Applied Sciences in Velp, The Netherlands.

The report contains an analysis about how to improve the agricultural water resource management of a large-scale farm in Romania by using the hydrological model SPHY (**S**patial **P**rocesses in **HY**drology). The agricultural sector still is the biggest not natural user of fresh water. Therefore a sustainable use of water in the agricultural sector is very important. I think that models like SPHY can make a contribution to a more sustainable water use. I enjoyed doing this research and I learned a lot of it.

Writing this Bachelor thesis would not have been possible without the help of several people. First I would like to thank the whole FutureWater-Team for the great time I had during my internship. I really enjoyed working in such a great company. Especially I would like to thank Peter Droogers, Wilco Terink and Gijs Simons for their useful feedback, help with the SPHY-modeling and collecting data and for the writing of handy python scripts to save valuable time. Furthermore I would like to thank Gé van den Eertwegh for convincing local people (from the farm and the university in Romania) to provide local data.

There are also two persons from Van Hall Larenstein University I would like to thank in particular. I want to thank Hermine de Wolf for providing me her network and for her endless help on finding a good internship. I want to thank my supervisor Sara Eeman as well, for her useful feedback and support during this internship.

Maren Wehling
Wageningen, 5th June 2014

Summary

The agricultural sector is the biggest not natural user of fresh water. Due to increasing world population, the water demand of the agricultural sector will rise in future. At the same time there are many possibilities to save water and the demand for a product, which can calculate actual evapotranspiration and soil moisture, grows. FutureWater developed a hydrological model, which can calculate both, called SPHY (Spatial Processes in HYdrology). Aim of this research is to find out how the agricultural water resource management of the large-scale farm Emiliana West Rom Ltd. in Romania can be optimized by using SPHY.

The 10,000 ha big farm Emiliana West Rom Ltd. is located in the Banat region (West Romania). This region knows warm and dry seasons in the summer and wet and cold seasons in the winter. 3000 ha of the clayish farm ground are irrigated by using surface water.

The used methods for this research are data inventory (local, global and sensor data) and hydrologic modeling with SPHY (preparation of input maps, run and calibration of the model and post processing). Furthermore different scenarios are created and analyzed.

After creating the input maps for the SPHY model, several model runs are executed. The results are compared to the measured values of the soil moisture sensors. The absolute difference in water content of the root zone between measured and modeled values is smaller at a root depth of 400mm than at a root depth of 600mm. The second calibration step is the change in seepage. By adding a seepage of 1.5mm/day the water content in the root zone nearly does not change and it is chosen not to use seepage in the following runs.

The next calibration steps includes different amounts of irrigation, based on the difference between potential and actual evapotranspiration. The absolute difference in water content becomes smaller, but stagnates when the evapotranspiration deficit becomes zero. For the last calibration step the static crop factors (one crop factor per land use for the whole year) have been changed into dynamic crop factors (different crop factors per growing stadium of the crops). This results in a higher water content during the begin of the growing season. The results of this run are seen as the best possible, because due to global data the difference between measured and modeled values can never be zero (measured values are sometimes even higher than the saturated water content in the model).

Several model runs are executed for different scenarios. Within the first scenario fixed irrigation (same amount of water every week) is compared with scheduled irrigation (dependent on the difference between field capacity and actual soil moisture). The second irrigation pattern results in a higher water content. Furthermore two scenarios of climate change (higher temperature and dry vs. wet seasons) are analyzed. In all cases the scheduled irrigation adapts easily to the new circumstances. So the conclusion can be drawn, that the agricultural water resource management at the study site can be optimized by using a scheduled irrigation, based on results of the SPHY model.

Based on the big differences between measured and modeled values, it is advised to do further research. First the model runs should be executed with local data for a better calibration. Second, research should be done on the reliability of the sensor data and the sensor data should be rescaled if necessary. At last research should be done on the irrigation patterns, based on the evapotranspiration deficit.

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1 Introduction

1.1 Background and motivation

In most countries, the agricultural sector is the biggest, not natural user of fresh water (according to Food and Agricultural Organization (FAO, FAO Water: Newsarchive, 2013)). Due to the increasing world population, the demand for agricultural products will rise in future. As a result of the higher demand for agricultural products, the water demand of the agricultural sector will rise as well. At the same time there are many possibilities to save water within the agricultural sector and make agricultural water use more sustainable.

More and more often there is a demand for a product or model that can calculate the soil moisture and the actual evapotranspiration to realize a more sustainable use of water. Water managers and farmers could optimize their agricultural water management by using such a product. Furthermore a product or model could forecast how much water for irrigation is needed in dry seasons. Thus water could not only be saved, but also crop yield could be increased and the water productivity (crop yield per used volume of water [kg/m^3]) could be improved by such a product.

FutureWater has developed a model for calculating soil moisture and actual evapotranspiration: SPHY (Spatial Processes in Hydrology (FutureWater, SPHY, Augustus 2012)). They want to use this model as an online-tool, so that farmers and water managers will get parcel oriented irrigation advice to improve their crop yield and save water.

1.2 Problem definition and research questions

The study site of this research is a large-scale farm, that is located in the region around the Banat, in Romania (see Figure 1-1). Within this region, plane grounds can be found, which are very suitable for agriculture. But in the Banat-region long-lasting dry seasons in the summer alternate with wet periods in the winter. Along with a lack of knowledge about irrigation techniques, this alternation has a negative effect on the crop yield. Therefore in this area a lot can be done to optimize the agricultural water management. To find out how the agricultural water resource management can be optimized by using SPHY, the following research questions have to be answered.

The main question is:

How can the agricultural water resource management at the study site be optimized by using SPHY?

This question is divided into several sub questions:

1. What do the landscape, the soil characteristics, the climate and the current agricultural water resource management of the study site look like?
2. How does the SPHY model work and which input data is necessary for the model?
3. How does the modeled soil moisture looks like compared to the observed soil moisture?
4. How can the agricultural water resource management be optimized by using the SPHY-model?

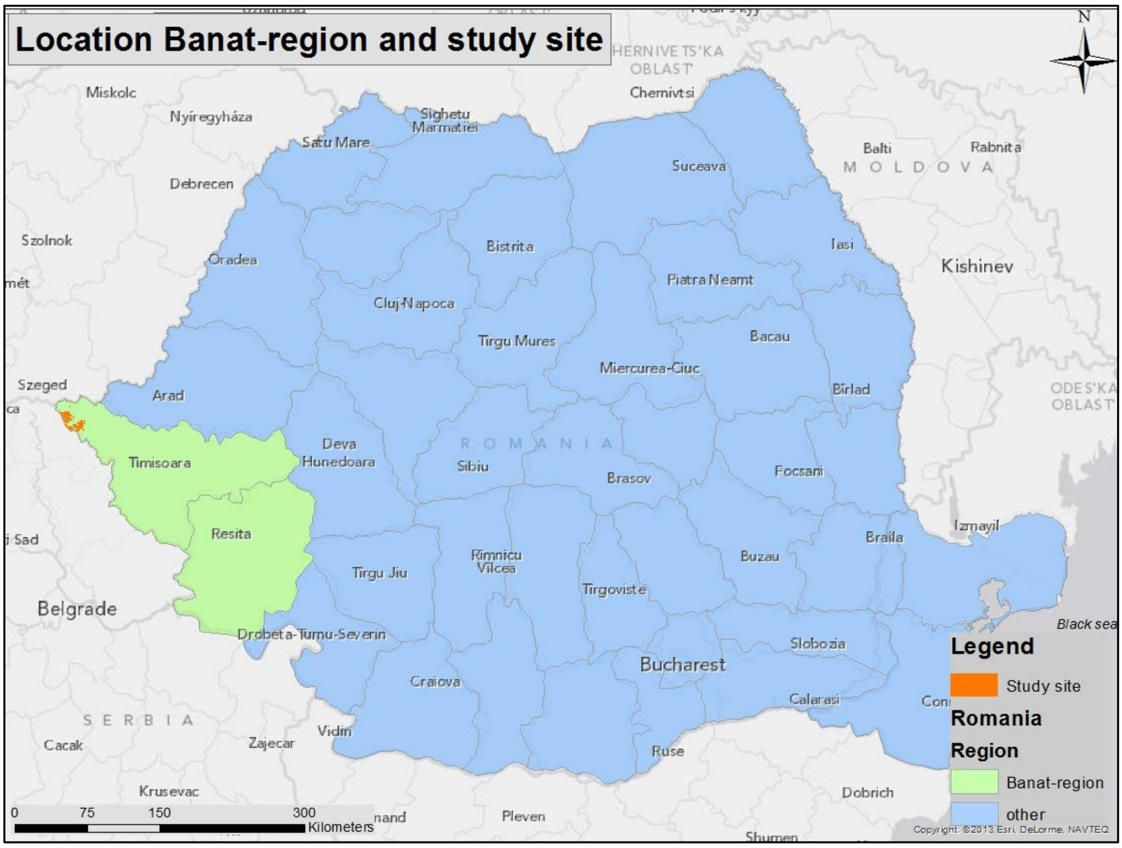

Figure 1-1: Location Banat-region and study site

1.3 Objective

Aim of this research is an optimization of the agricultural water resource management in the study site, by using SPHY. In this study, optimized agricultural water resource management is defined as: i) obtain the largest crop yield possible, and ii) use the smallest amount of irrigation water possible. The study site is used as pilot area. If the model is successful for this study site, it can be used for other areas.

1.4 Method

Within this research different methods are used. First a literature study is done to find more information about the study area and to find global data (soil, land use etc.) from the internet. Together with local data from the study site and from soil moisture sensors and weather stations from DACOM ("high-tech company that develops and supplies specialized hardware, software and online advisory services to arable farms and the agribusiness around the world" source: (DACOM: Innovation and Dacom, 2014)), this data is analyzed in a data inventory.

After analyzing the available data, input maps are created for the SPHY-model. The SPHY model is a raster based, hydrological model for calculating soil moisture and actual evapotranspiration. With the input maps the first model run is executed. Then several parameters are changed, e.g. root depth, to calibrate the model. The final results are imported to ArcGIS and are compared with measured data.

To analyze how the agricultural water resource management can be improved by SPHY, different scenarios are created (e.g. different irrigation patterns, climate change) and executed in different model runs. The results of the scenarios are compared with the final results and analyzed. A more detailed method description can be found in chapter three.

1.5 Scope

The research takes place within certain limits and has to fulfill several conditions. These boundaries and conditions are described below.

Within this research only one study site will be analyzed, because there is only one farm participating in the project. The model will be calibrated based on the measured data of 2013 only, because no measured data is available for other years. The model, used in this research, will be calibrated as good as possible. But because mostly global data is used, it will be difficult to model the same as measured data. For calibration, the soil parameters (rooting depth etc.) and the amount of irrigation will be changed. Also dynamic and static crop factors will be used. If the differences between different calibration steps will become evanescent, the calibration will be stopped and the results which are most similar to the measured data are used as final results.

Another condition is, that this research must make a contribution to a sustainable water use in the agricultural sector. This condition will be fulfilled, by analyzing how the agricultural water resource management can be optimized.

1.6 Thesis outline

In chapter two an area description of the study site can be found. Chapter three contains a detailed description of the used method and the SPHY model and in chapter four the model results are described and compared to measured data. How the SPHY model can optimize the agricultural water management is discussed in chapter five, based on different scenarios. The conclusion, discussion and recommendations can be found in the last chapter.

1.7 Target group

This report is written for FutureWater, the farmers of the study site and everyone who is involved in the OPI Romania project.

2 Area description

The study area is a large-scale farm in the Banat region in Romania: Emiliana West Rom Ltd.. In the paragraphs below the characteristics and the current agricultural water resource management of the study area are described.

2.1 Location

Emiliana West Rom Ltd. is a modern agricultural company, located in the western part of Romania, at the border to Serbia (see Figure 2-1). The farmlands are located at both sides of the municipalities Dudestii Vechi and Valcani and have a total size of more than 10,000ha. 3000ha of the farmland are irrigated. Furthermore Emiliana West Rom Ltd. has ca.1200 cows for the meat production.[1]

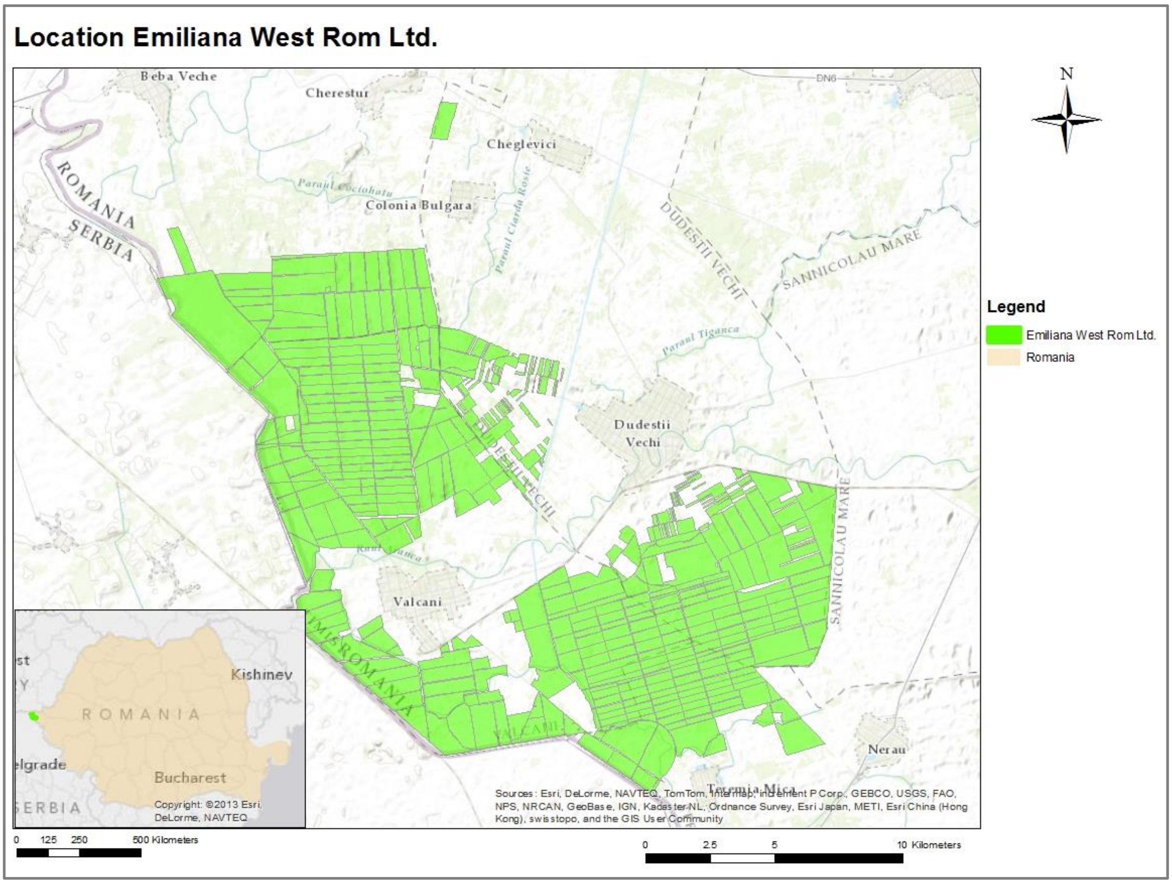

Figure 2-1: Location Emiliana West Rom Ltd.

[1] (Emiliana West Rom: Agricultura, 2012)

2.2 Digital Elevation Map

The elevation within the study area differs from 70 to 80 MASL (see Figure 2-2). Nearly the whole area has a height between 70 and 75 MASL. The southeast of the area is situated higher with an average height of 77 MASL. Only small parts of the study area are higher than 78 MASL.

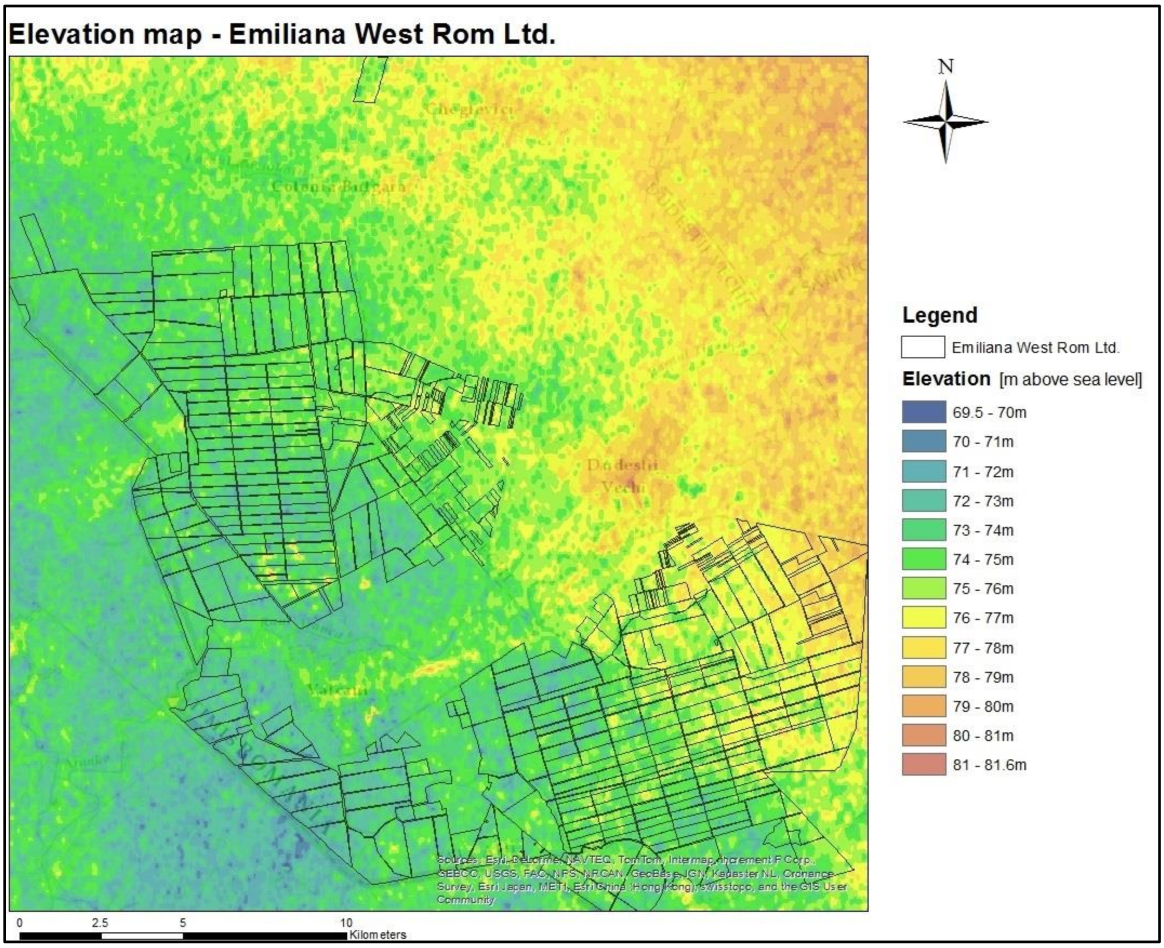

Figure 2-2: Elevation map - Emiliana West Rom Ltd. (Source: **(EuropeanEnvironmentAgency, 2013)**)

2.3 Soil

Within and around the study area, seven different soil types of five main classes can be found (see Figure 2-3). Eutric vertisols is the most dominant soil type within the study area, followed by mollic gleysols and calcaric fluvisols. Furthermore there are small parts of calcaric, haplic and gleyic phaeozems. In the region around the farm the same soil types and calcic chernozems can be found. In Table 2-1, the five main classes are described.

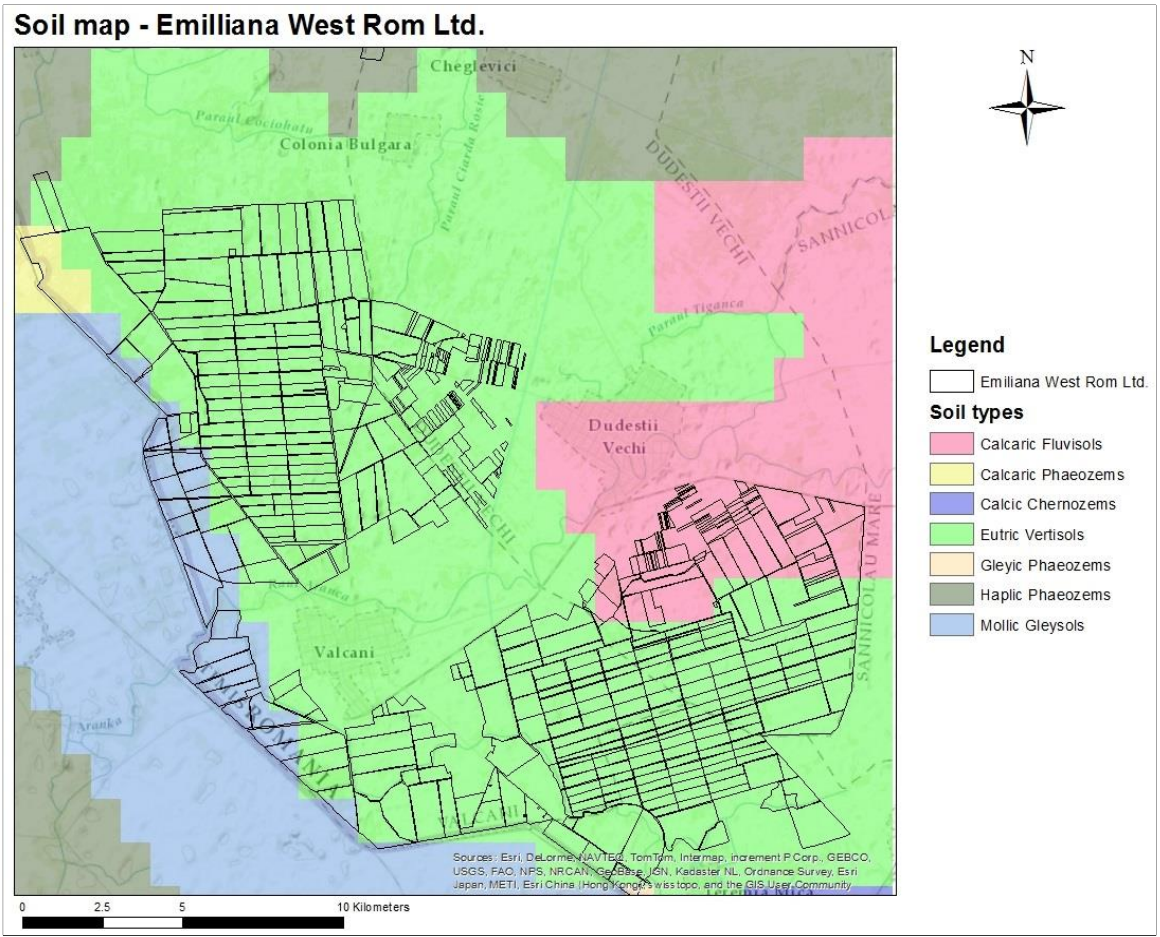

Figure 2-3: Soil map - Emiliana West Rom Ltd. (Source: **(IIASA: Harmonized World Soil Database)**)

Table 2-1: Main classes soil (Source **(IIASA: Harmonized World Soil Database)**)

Soil type	Description
Phaeozems	Soils with a thick, dark topsoil rich in organic matter and evidence of removal of carbonates
Vertisols	Dark-colored cracking and swelling clays
Fluvisols	Young soils in alluvial deposits
Gleysols	Soils with permanent or temporary wetness near the surface
Chernozems	Soils with a thick, dark topsoil, rich in organic matter with a calcareous subsoil

Vertisols are dominant within the study area. For agriculture this means, that water will infiltrate slowly into the ground. Because of slow infiltration a lot of water will evaporate, but also the drainage to the subsoil will be slower, so the water can stay longer in the root zone.

According to the field visit report[1], the soil within the study area is mainly light to heavy clay (chernozem) and is showing cracks when drying. The top clay layer is 60cm deep and lies on sandy subsoil. Chernozems are less permeable than vertisols. But because both soil types are clayey the effects on agriculture will be similar. Actually there could be small differences in model results, if the soil type would be changed in the model.

2.4 Climate

For this research a combined data set of climate data is used. The climate data comes from two local stations (Emiliana Farm and Emiliana Silos) and from the Szeged weather station of weather underground[2]. The combined data set can be found in appendix 2.2.3. The following parameters are analyzed:

- Minimum temperature
- Average temperature
- Maximum temperature
- Precipitation

Figure 2-4 shows the minimum, average and maximum temperatures per day in 2013. The region normally has cold winters and warm summers with a difference in temperature of more than 20˚C.
The average day temperature in 2013 differs between -5˚C and 29˚C. On 29th July, 8th and 9th August the highest maximum temperature is measured (39˚C). The coldest temperatures are measured on 8th January, 17th and 28th march (-8˚C). The warmest month was Augustus with an average temperature of 24˚C and the coldest month was January with an average temperature of 1˚C.

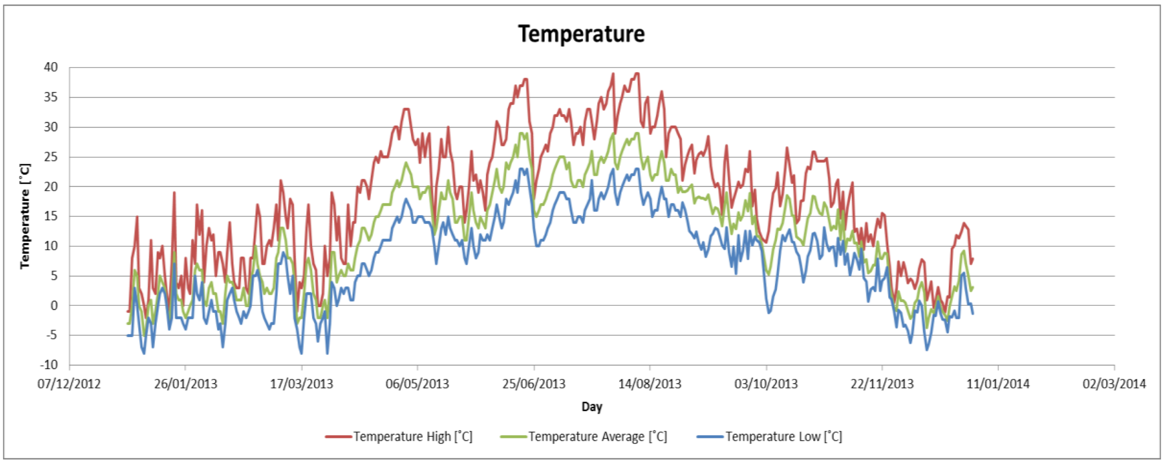

Figure 2-4: Average, minimum and maximum temperature of 2013, based on three weather stations (Emiliana Farm, Emiliana Silos and Szeged)

Figure 2-5 shows the total precipitation per month and the maximum precipitation per month in mm/day. The wettest month of 2013 is March with a total precipitation of 103mm, followed by May (91.8mm) and September (61.4mm). December was a very dry month with nearly no precipitation (0.9mm). The highest values are measured on 24th June (25.9mm/day), 16th October (22.1mm/day), 29th September (20.5mm) and 21th March (20.3mm). The total amount of precipitation in 2013 was ca. 560mm, so it was an average year.

[1] (Eertwegh, 2013)
[2] (Wunderground: Waarschuwing Historische gegevens voor ICSONGRD3)

Normal the rainfall amounts 60-70mm/month, but nowadays longer periods of drought occur and local rainfall can be extreme.

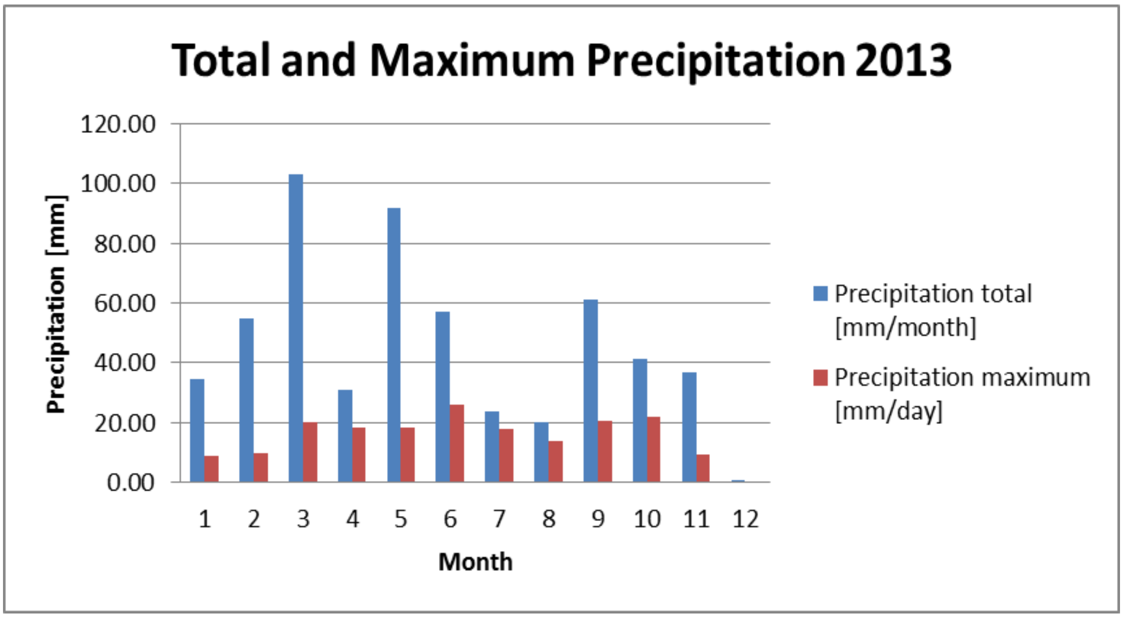

Figure 2-5: Total and maximum precipitation per month of 2013, based on three weather stations (Emiliana Farm, Emiliana Silos, Szeged)

2.5 Land cover

Within the study area 3000ha is irrigated (see Figure 2-6). The other farmlands are non-irrigated. Furthermore urban areas, bare soil and nature can be found within and around the study area. There are also some water courses within the area, for example the 117 km long Aranca river, which flows through Dudestii Vechi.

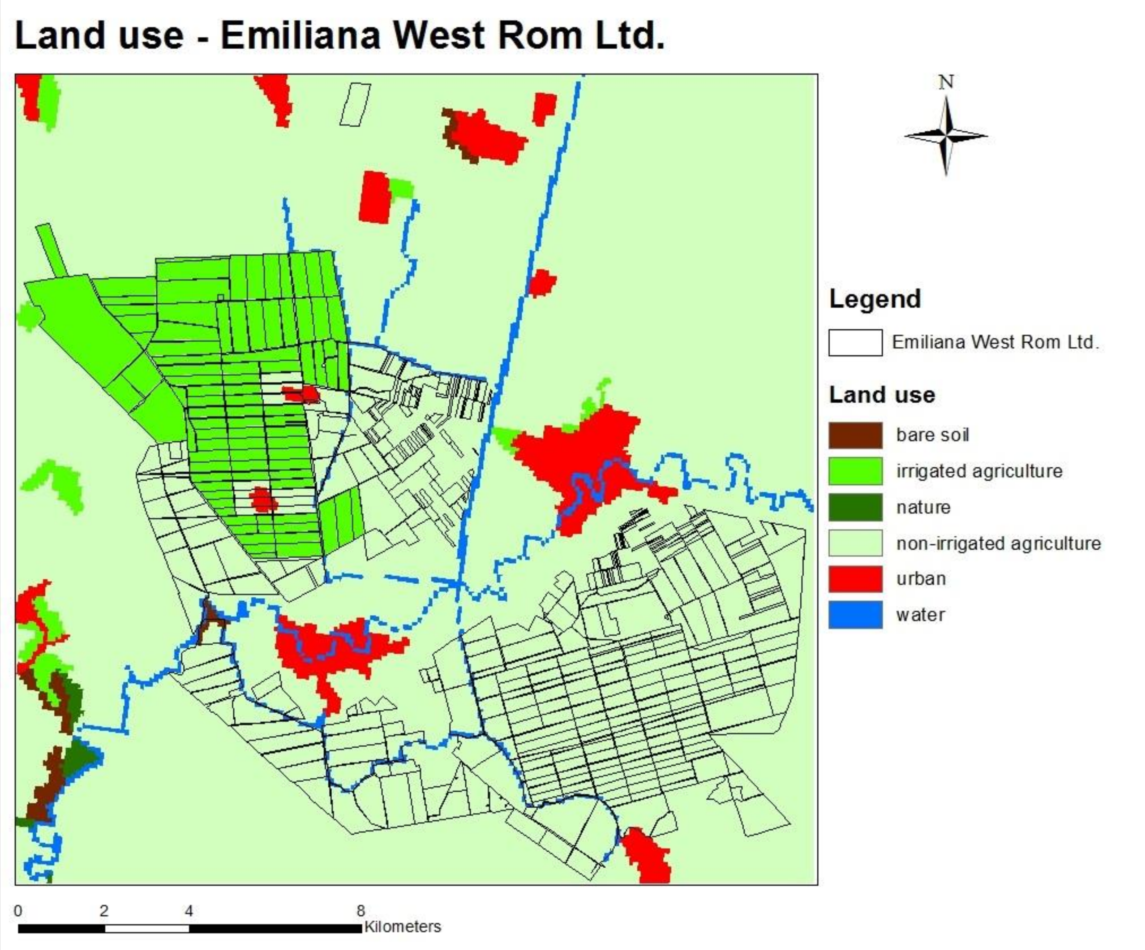

Figure 2-6: Land use - Emiliana West Rom Ltd.

2.6 Current agricultural water resource management

The irrigation system used in the study area is a Valmont pivot irrigation model 8120 (see Figure 2-7).[1] The water for the irrigation system comes from the surface water, via a 40km long main channel. The groundwater is located 2-3m below surface, but is not used because it is brackish and salty due to soil salinity problems. During the communist era, subsurface drainage discharged the brackish water, but this system is not working anymore. The current irrigation surface has a size of around 3000ha. Because of the dry seasons, irrigation takes place four times during one growing season. According to the results of the field visit in 2014, over-irrigation has taken place often in the last years, which leads to an inefficient water use and was destructive for the crop yield.

[1] (Emiliana West Rom: Agricultura, 2012)

The crops which are grown most are corn and soybeans (by using 50% of the total surface).[1] Table 2-2 shows all cultivated crops and their approximate growing season. Because no information has been available about the locations of the different crops, an average growing season from begin April till half September and average crop factors are assumed (see appendix 2.5).

Figure 2-7: Valmont irrigation system model 8120 (Source: **(Valmont: Center pivots, 2014)**)

Table 2-2: Growing seasons (source: **(Crop-R, 2014)**

CROP	GROWING SEASON
Sunflower	15 March to 1 September
Corn	1 April to 1 October
Sugar beet	10 March to 10/15 September
Soybeans	1 April to 15 September
Rapeseed/canola	1 September to 15 June
Wheat	20 September to 1 July

[1] (Eertwegh, 2013)

3 Method

This chapter contains the used methods in chronological order. The first paragraph describes the preliminary steps such as literature study and the second paragraph describes the inventory of data from different sources. All processes of hydrological modeling from preparing data to running the model and post processing are described in paragraph 3.3. How to create the different scenarios is discussed in paragraph 3.4

3.1 Preliminary steps

Before starting with the data inventory and hydrological modeling, a literature study is necessary to find additional information on the study area and background information on the SPHY model.

The study area Emiliana West Rom Ltd. is chosen as a pilot area, because there are many possibilities to improve the agricultural water resource management within this region. The SPHY model can improve the irrigation within the region by calculating soil moisture and actual evapotranspiration. For more information on SPHY see paragraph 3.3.

3.2 Data inventory

The used data for modeling and calibration comes from different sources:

- Local data: data provided by the study site, field reports, internet and literature study
- Sensor data: data from soil sensors provided by DACOM
- Global data sets: from internet and literature study

In the paragraphs below the different data sets are described.

3.2.1 Local data

The study site has provided a shape file with the boundaries of the farm lands. The total size of the farmlands is ca. 10,000ha. This information matches with the information on the company website ((Emiliana West Rom: Agricultura, 2012). Furthermore information about irrigation systems and crop sorts (see chapter two) can be found on the website.

3.2.2 Sensor data

For calibrating the model, soil moisture measurements are necessary. The soil moisture is measured on different depths, by soil sensors of DACOM. The sensors are placed after seeding and are removed before harvesting. For that reason data is not available for every day of the year.

Furthermore DACOM has measured air temperature, reference evapotranspiration and precipitation with two weather stations within the study area (Emiliana Farm and Emiliana Silos). Because there is nearly no difference between the data of the two stations (see appendix 1.1.1), the average between these stations is taken. The data starts at 28th August 2013 (see appendix 1.1.2 for the DACOM-climate data). For modeling a whole year, this data is combined with global climate data (see paragraph 3.2.3).

The locations of the soil moisture sensors and weather stations of DACOM can be found in Figure 3-1.

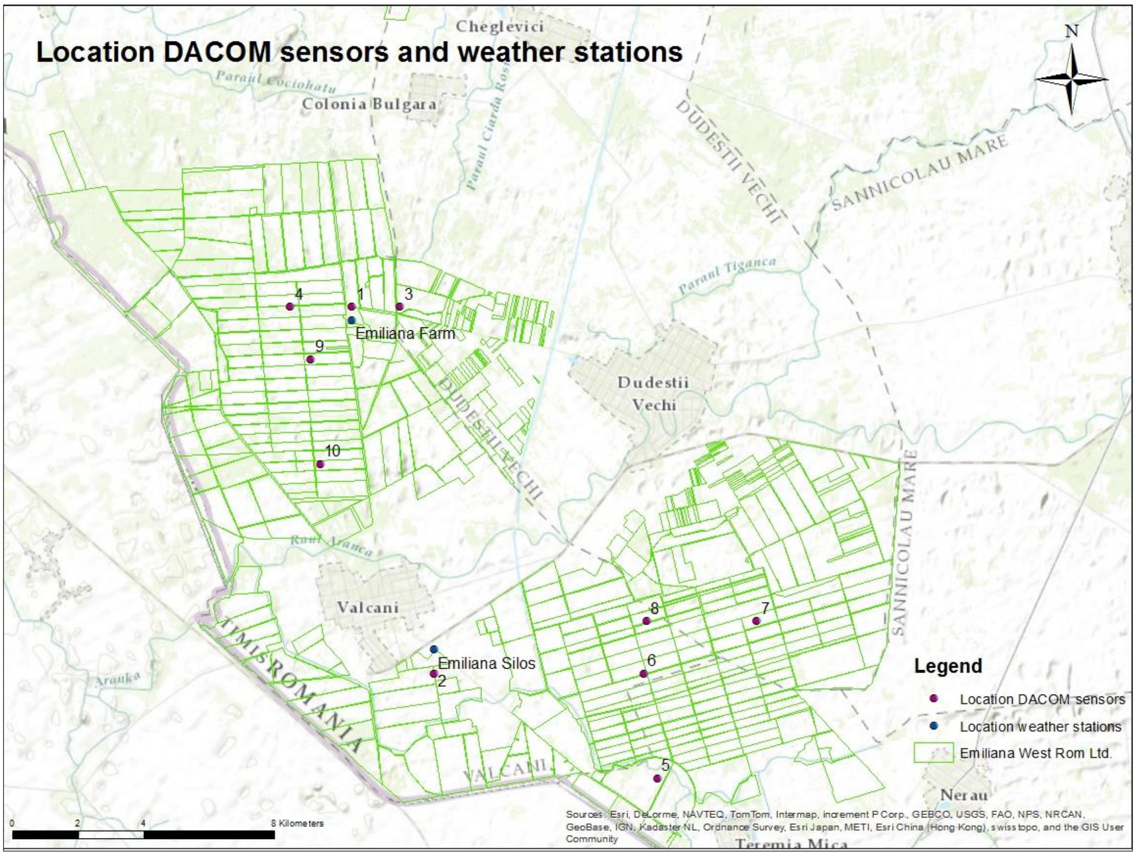

Figure 3-1: Locations DACOM sensors and weather stations

3.2.3 *Global data sets*

Not all of the necessary input data is provided by the study site. So for some input maps, global datasets are used. Below, different global data sets are described per topic (DEM, climate, soil and land cover). An overview of all global data sets can be found in appendix 2.1, as well.

DEM:

One of the necessary input maps for the SPHY-model is a DEM (Digital Elevation Model). Several organizations and institutes offer global DEMs:

- NASA – Jet Propulsion Laboratory: Shuttle Radar Topography Mission[1]
- Aster Global Digital Elevation Model (GDEM)[2]
- European Environment Agency[3]

There is chosen to use the DEM of the European Environment Agency (EEA), because the EEA offers a detailed DEM-grid with a resolution of ca. 30m. The DEM-map of the project area can be found in chapter two.

CLIMATE:

Another important input for the model is climate data (precipitation and temperature). Because the local data is incomplete, global data is needed to complement the local data. Global data is available from the following sources:

- Climatic Research Unit (CRU)[4]
- GSOD database [5]
- Weather underground [6]

Actually CRU has historical climate data till 2010 and monthly values only. Because climate data (daily values) of 2013 is necessary, CRU is not suitable for this research. GSOD is not chosen, because no nearby stations were available.

The dataset of weather underground is chosen, because it includes all necessary data (maximum, average and minimum temperature and precipitation). The nearest weather station is located in Szeged, Hungary (see Figure 3-2).

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[1] (NASA: Jet Propulsion Laboratory: Shuttle Radar Topography Mission)
[2] (Aster Global Digital Elevation Model)
[3] (EuropeanEnvironmentAgency, 2013)
[4] (Climate Research Unit: Data)
[5] (NOAA Satellite and Information Service: Global Surface Summary of Day)
[6] (Wunderground: Waarschuwing Historische gegevens voor ICSONGRD3)

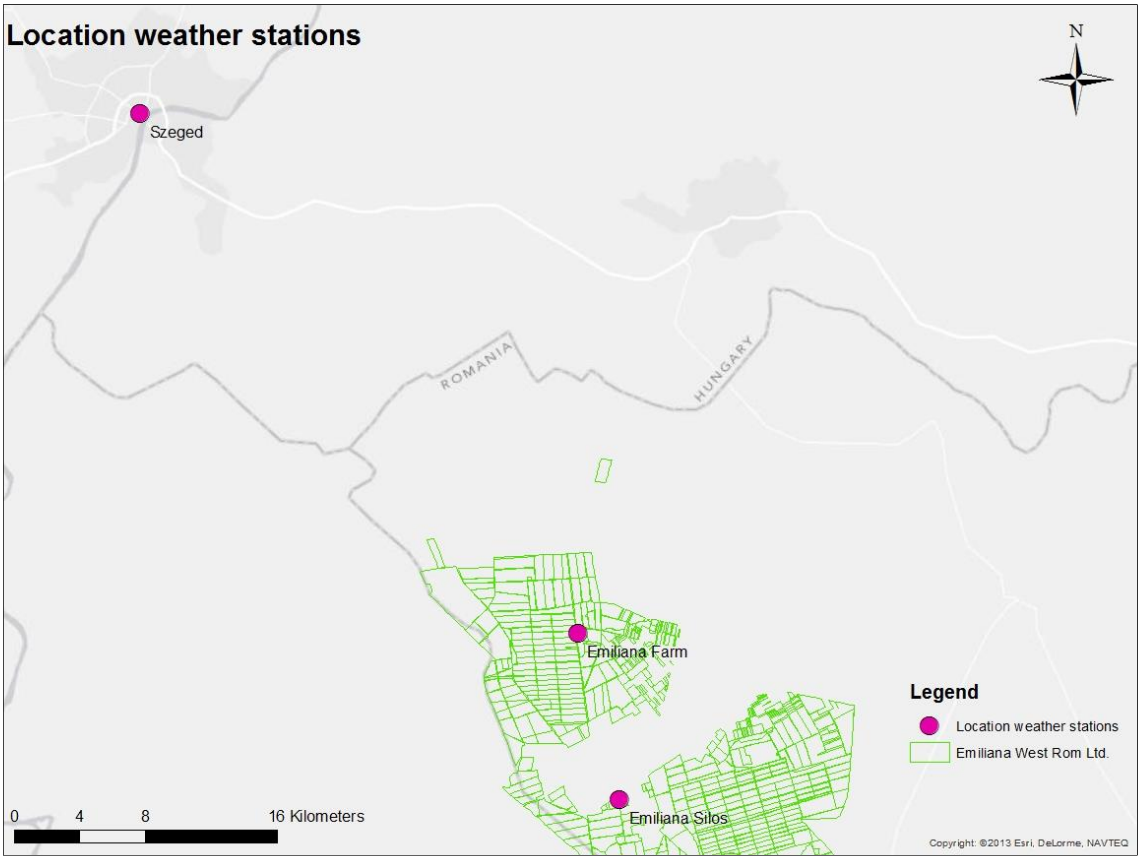

Figure 3-2: Location weather stations

Actually some maximum and minimum temperatures are too high, respectively too low. Because the average temperature seems to be right, the data is corrected, by determining a maximum allowed difference of 10˚C between average and maximum temperature and a maximum allowed difference of 6˚C between average and minimum temperature. The maximum allowed differences are determined based on the average difference between the non-extreme values of minimum and maximum temperature with the average temperature. If the difference between values is bigger than the maximum allowed difference, the value is changed to the sum of the average temperature and ten, respectively changed to the difference of the average temperature and six (see Figure 3-3 for the original and corrected climate data). Furthermore data of four days is missing. For these days values are determined similar to the values of the days before and after these days. The corrected climate data can be found in appendix 2.2.

Because local data starts at 28th August, and the difference between the data of weather underground and the local data is small (see appendix 2.2.2), the dataset of wunderground is combined with local data, measured by the DACOM weather stations.

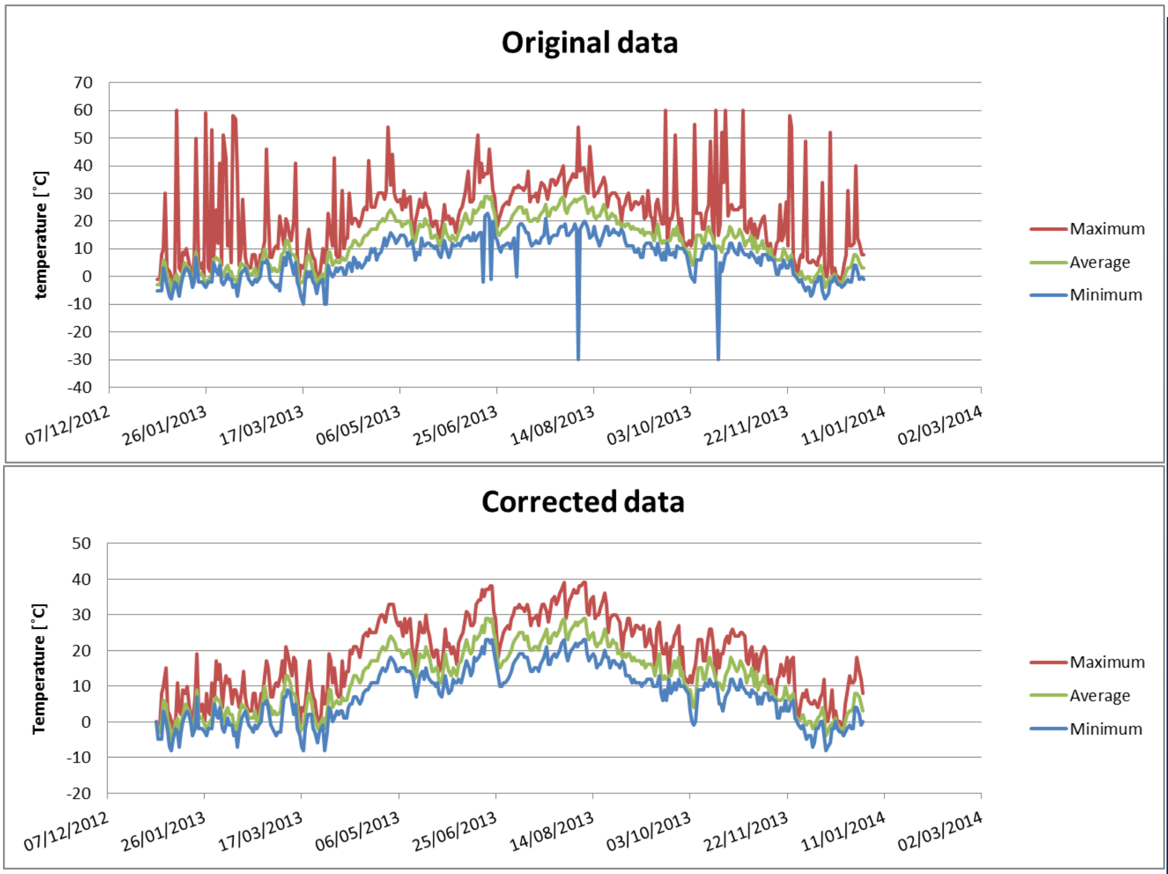

Figure 3-3: Correction of climate data

SOIL:

For the SPHY model not only the soil type is important, but also other factors connected to the soil type, e.g. field capacity. So a dataset is needed, which contain more than only the soil type. Below the available data sets of different institutes and organizations are described.

Digital Soil Map of the world[1]*:*

The 'Digital Soil Map of the World' (DSMW) is provided by FAO. Because of the world scale, the polygon file is not very detailed. According to the DSMW there are only two different soil types within the study area: calcic chernozems and calcic fluvisols (see appendix 2.3.1). Therefore the DSMW is not chosen as input map for the SPHY model.

ISRIC[2]*:*

The soil map provided by ISRIC, is a soil map for whole East Europe. According to this polygon file there is only one soil type within the study area (see appendix 2.3.2). This is not detailed enough for this research. Therefore this map is not chosen as input.

[1] (FAO: GeoNetwork)
[2] (ISRIC - World Soil Information)

Harmonized World Soil Database[1]*:*
The 'Harmonized World Soil Database' (HWSD) is a raster grid with a resolution of 30 Arc seconds (~1km). Though it has a world scale as well, it is more detailed than the other two available soil maps. According to HWSD there are seven different soil types within the area. Also additional data is available for the HWSD (e.g. field capacity and wilting point; source: (Terink, 2013)), which is necessary for the model. The HWSD soil map is chosen as model input and can be found in chapter two.

LAND COVER:
Because there is no local data available about land cover on the moment, global data sets are needed. Below three data sets are described. The maps of the datasets below can be found in appendix 2.4.

Global land cover facility[2]*:*
The 'Global land cover facility'(GLCF) map has a resolution of ca. 1km. This is too rough as input map. Furthermore there are no irrigated areas, according to this map. Therefore this map is not chosen as input map for the SPHY model.

Global irrigated Area map[3]*:*
The 'Global Irrigated Area Map' (GIAM) is a raster grid with a resolution of several kilometers. It describes the size of the areas, which are equipped for irrigation. Within the study area, 51.83% of the equipped areas is actually irrigated. Because the grid is to rough and the data is not up-to-date, this map is not used.

EEA[4]*:*
The land cover map of the EEA is, with a resolution of 100m, more detailed than the GLFC map. But also within this maps irrigated areas are not included. Therefore this map has to be changed to a land cover map based on this map and data from the farm website (source: (Emiliana West Rom: Agricultura, 2012)). How the land cover map is made is described below.

Changed land cover map:
Because the available land cover maps do not contain irrigation areas a new map is made with six classes: irrigated agriculture, non-irrigated agriculture, bare soil, urban, nature and water. The map is made based on the EEA land cover map and the total size of the irrigated area as described on the company website (3000 ha, source: (Emiliana West Rom: Agricultura, 2012)).

The land cover classes of the EEA land cover map are translated to the new classes. In Table 3-1 the translations can be found. The EEA land cover class "complex cultivation patterns" is assumed to be irrigated agriculture. This results in one irrigation area within the study area and several irrigation areas around the farm. Around the irrigation area within the study site, irrigation areas are added, so that the total irrigation area within the study site counts 3000ha (see Figure 3-4). The changed land cover map can be found in chapter two.

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[1] (IIASA: Harmonized World Soil Database)
[2] (Global Land Cover Facility)
[3] (FAO, aquastat, & UniversitaetBonn, FAO: Global Map of Irrigation Areas (GMIA))
[4] (EEA: Corine Land Cover 2006 raster data)

Table 3-1: translation to new land cover classes

Land cover class EEA				Land cover class new	
Grid code	***Label 1***	***Label 2***	***Label 3***	***Land cover ID***	***Land cover description***
2	Artificial surfaces	Urban fabric	Discontinuous urban fabric	4	Urban
3	Artificial surfaces	Industrial, commercial + transport units	Industrial or commercial units	4	Urban
12	Agricultural areas	Arable land	Non-irrigated arable land	2	Non-irrigated agriculture
18	Agricultural areas	Pastures	Pastures	2	Non-irrigated agriculture
20	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	1	Irrigated agriculture
21	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture with significant areas of natural vegetation	3	Bare soil
26	Forest + semi natural areas	Scrub and/or herbaceous vegetation associations	Natural grassland	5	Nature
29	Forest + semi natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland scrub	5	Nature
35	Wetlands	Inland wetlands	Inland marshes	6	Water
40	Water bodies	Inland waters	Water courses	6	Water

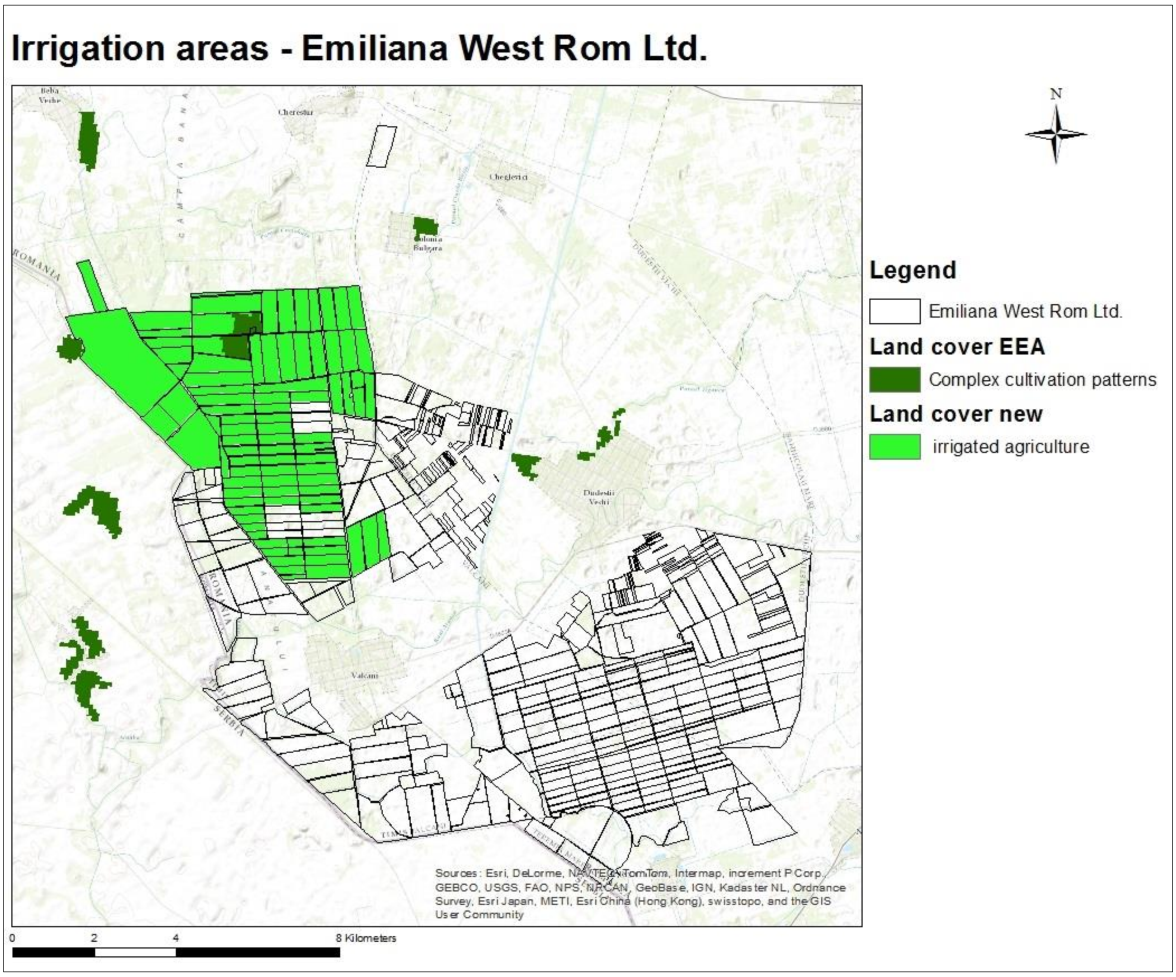


Figure 3-4: Irrigation areas of modified land use map, as used for this study

Every land use class has an individual crop factor (Kc-factor). Crop factors are used to calculate the potential evapotranspiration, based on the reference evapotranspiration:

$$ET_{pot} = K_c * ET_{ref}.$$

The crop factors can be the same throughout the year (static calculation) or be different for the agricultural grounds (dynamic calculation). To calculate with static Kc-factors, a table has to be created with one crop factor per land use class. The crop factors for the agricultural grounds are determined by taking the average of the crop factors in mid-season of all planted crops. The crop factors per plant are determined based on the crop factors given by FAO[1]. The dynamic crop factors are also determined based on the crop factors given by FAO, but then the average is taken per season. Normally difference is made between different crops, but because there is no information available about the location of the crops, the average of the crop factors is taken.

[1] (FAO, 1998)

3.3 Hydrological modeling

The hydrological modeling within this research is done with the SPHY model. In the paragraphs below the SPHY model, the preparation of input data, the model run and post processing steps are described.

3.3.1 Description SPHY model

The SPHY model is a raster model, consisting of a two soil layers (root zone and sub zone) and a vegetation layer (see Figure 3-5). In this case the model has a resolution of 30m. Incoming fluxes are precipitation and seepage upward, outgoing fluxes are actual evapotranspiration, surface runoff, drainage from the root zone and drainage from the second soil layer (subsoil) and seepage downward. Through capillary rise and percolation there is exchange of water between the root zone and the sub soil. The characteristics of the two layers are based on soil physical properties, which define the incoming and outgoing fluxes. The fluxes are calculated based on the actual soil moisture within the layers. [1]

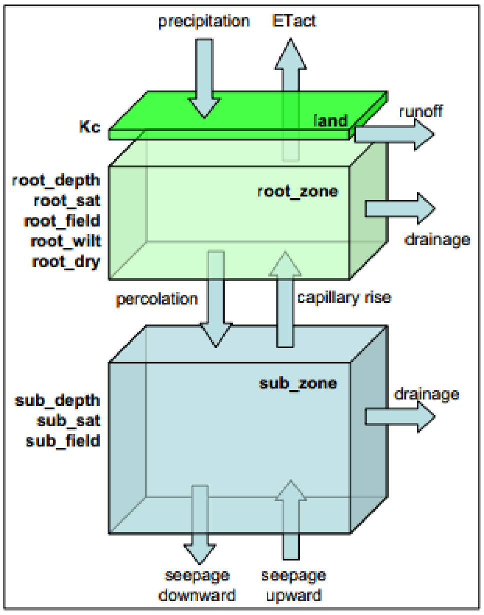


Figure 3-5: Schematization SPHY (Source: (FutureWater, Augustus 2012))

3.3.2 Preparation of input data

To run the SPHY model, the input maps have to be created first. In the table below the input maps and the steps, how to create them, are described. The maps are created by using ArcGIS and PCRaster (PCR). PCR is a Geographical Information System which is used for environmental modeling (e.g. hydrological modeling), created by the Department of Physical Geography, Utrecht (The Netherlands)[2].

The first map, which has to be created, is the clone map. With the clone map, all input maps are clipped and resampled, so that every map has the same projection, extension and cell size. For more information on creating the input maps see the SPHY-tutorial (source: (FutureWater, SPHY tutorial, 2014)).

[1] (FutureWater, SPHY, Augustus 2012)
[2] (PCRaster-Team, 2011)

Table 3-2: Input maps

Input maps / tables	Name in model	Description	Unit	Processing
Basins	basins.map	Map with sub basins. Because the study area is not a natural catchment, but a large scale farm, it is assumed that the whole area is one basin.		It is assumed that the whole area is one basin. Therefore the boundary raster (see clone map) is imported to SPHY as basin map.
Calibration points	calibration_points.map	Time series of the model output will be created at these locations. The calibration points have the same location as the DACOM sensors, so that output from the model can be easily compared to measured data.		The table with the locations of the soil moisture sensors is imported to ArcGIS and is converted into a layer file. Then the point-layer is changed into a raster file, converted into an ascii-file and imported to SPHY by using PCR.
Clone	clone.map	Boundary map for resampling and clipping all input maps.		For creating the clone map, first the boundary of the area has to be determined. Second the boundary polygon has to be converted into a raster using the right cell size (30m) and coordinate system (in this case WGS_1984_UTM_ZONE_34N). At the end a new boolean map has to be created with the same properties as the boundary raster.
DEM	dem.map	Height grid of the study area.	MASL	Global grid is clipped and resampled with the clone map.
Land use	landuse.map	Map with different land use classes (irrigated agriculture, non-irrigated agriculture, urban, bare soil, nature and water)		First the land use classes of the global grid are changed into six classes (irrigated agriculture, non-irrigated agriculture, urban, bare soil, nature and water). Then the raster is clipped and resampled with the clone map.
Latitude	latitude.map	Map with latitudes, based on the location of the study area.	WGS84 degrees	The value of the boundary raster is changed into the value of the latitude. Then the raster is converted to ascii and is imported by PCR.
Slope	slope.map	Map with slope of the study area based on the DEM.	m/m	The slope map is created based on the DEM by using the slope function of PCR.
Soil map	soil.map	Map with different soil types. Based on the soil types, maps for each soil parameter are created.		The global soil grid (HWSD) is clipped and resampled with the clone map. Then it is converted to an ascii-file and imported to SPHY by using PCR.
	root_dry.map	Permanent wilting point root zone (different per soil type).	mm/mm	First a table is made with the permanent wilting points of the root zone per soil type. Then the map is created by using the soil map and the lookup function of PCR.
	root_field.map	Field capacity root zone (different per soil type).	mm/mm	First a table is made with the field capacity of the root zone per soil type. Then the map is created by using the soil map and the lookup function of PCR.

	root_ksat.map	Saturated hydraulic conductivity root zone (different per soil type).	mm/day	First a table is made with the saturated hydraulic conductivity of the root zone per soil type. Then the map is created by using the soil map and the lookup function of PCR.
	root_sat.map	Saturated water content root zone (different per soil type).	mm/mm	First a table is made with the saturated water content of the root zone per soil type. Then the map is created by using the soil map and the lookup function of PCR.
	root_wilt.map	Wilting point root zone (different per soil type).	mm/mm	First a table is made with the wilting point of the root zone per soil type. Then the map is created by using the soil map and the lookup function of PCR.
	sub_field.map	Field capacity subsoil (different per soil type).	mm/mm	First a table is made with the field capacity of the subsoil per soil type. Then the map is created by using the soil map and the lookup function of PCR.
	sub_ksat.map	Saturated hydraulic conductivity subsoil (different per soil type).	mm/day	First a table is made with the saturated hydraulic conductivity of the subsoil per soil type. Then the map is created by using the soil map and the lookup function of PCR.
	sub_sat.map	Saturated water content subsoil (different per soil type).	mm/mm	First a table is made with the saturated water content of the subsoil per soil type. Then the map is created by using the soil map and the lookup function of PCR.
Precipitation	prec0000.***	Maps with total precipitation per day (one map for each day).	mm/day	To have a warm-up year, the climate data of 2013 is put into a table twice (one time as 2012 warming-up year and one time for the real results). Then the table is converted to maps (one map for each day) by using the script *make_climate_maps.py*.
Temperature average	tair0000.***	Average temperature per day (one map for each day)	˚C	See precipitation
Temperature maximum	tmax0000.***	Maximum temperature per day (one map for each day)	˚C	See precipitation
Temperature minimum	tmin0000.***	Minimum temperature per day (one map for each day)	˚C	See precipitation
Crop factors	kc.tbl// kc00000.***	Table, respectively maps with crop factor (Kc) per land use.	(-)	Based on FAO, the crop factors per land use are determined. Then the land use codes and crop factors are put into one table, respectively every day get a map with different crop factors.

3.3.3 *Model run and calibration*

After creating the input maps and tables, all modules of SPHY, that are not required for the current study, need to be turned off in the model configuration file. Furthermore the start and end date have to be determined within this file. In this case the start date is 1st January 2012 and end date is 31st December 2013, so that there will be one “warming-up” year to get good initial conditions. After changing the configuration file, the first model run can be executed by running the script “sphy.py”. After the first run, several model runs with changes in input are executed until the results are satisfactory and similar to the measured values. In the table below, the most important calibration steps are described.

Table 3-3: Calibration steps

Case	Root depth	Kc static/dynamic	Irrigation	Seepage
Case 1	600mm	Kc static	No irrigation	0
Case 2	400mm	Kc static	No irrigation	0
Case 3	600mm	Kc static	No irrigation	1.5mm upwards
Case 4	400mm	Kc static	No irrigation	1.5mm upwards
Case 5	400mm	Kc static	$ET_{pot} - ET_{act}$	0
Case 6	400mm	Kc static	$(ET_{pot} - ET_{act})*2$	0
Case 7	400mm	Kc static	$(ET_{pot} - ET_{act})*5$	0
Case 8	400mm	Kc static	$(ET_{pot} - ET_{act})*10$	0
Case 9	400mm	Kc static	$(ET_{pot} - ET_{act})*20$	0
Case 10	400mm	Kc dynamic	$ET_{pot} - ET_{act}$	0
Case 11	400mm	Kc dynamic	$(ET_{pot} - ET_{act})*20$	0

First the root depth is changed from 600 to 400mm, because the measured soil moisture is lower in the first 400mm than in the last 200mm. In the next step seepage is simulated to analyze how big the influence of seepage on soil moisture is. Because the soil measurements are done during growing season, irrigation has to be simulated as well. Different amounts of irrigation are analyzed in the third step. The difference between potential and actual evapotranspiration is hereby used as basis to calculate the amount of irrigation water, so that the amount of irrigation is dependent on the climate. Another reason for why it is based on the difference between potential and actual evapotranspiration is, that a difference above zero means that there is a water shortage and so not enough water is available for the crops.

The last calibration step is to change the crop factors from static (same crop factor throughout the year) to dynamic (crop factors dependent from size of crop). By using dynamic crop factors the different growing stadiums of the crops are taken in account. The results of the different calibration steps are described in chapter four.

3.3.4 *Post processing and comparing results*

During calibration the results are compared to measured data, by importing the output time series into Excel. The results which are most similar to the measured data are also imported to ArcGIS to create maps of soil moisture and evapotranspiration. These maps can be compared to the measured data as well.

3.4 Creating scenarios

To analyze how agricultural water management can be improved by using SPHY, scenarios are created. Within these scenarios different irrigation patterns and climate scenarios are used and the input data is changed based on these scenarios. After creating the scenarios the model runs are executed with the changed input data. The different scenarios are described below. The results of the scenarios are described and analyzed in chapter five.

3.4.1 Scenario 1: Fixed vs. scheduled irrigation

The irrigation pattern can be the same every time, independent of actual soil moisture and climate (fixed irrigation) or changes from time to time, dependent on soil moisture and climate (scheduled irrigation).

To calculate the results of an fixed irrigation, a weekly pattern will be simulated. Therefore the total amount of irrigation of the year 2013 of case 11 (see paragraph 3.3.3) is divided by the amount of weeks during growing season. This results in ca.18mm/week. The 18mm are added to the precipitation one time a week during growing season.

Aim of an irrigation pattern dependent on actual soil moisture and climate is a soil moisture that is equal to the field capacity. Therefore the amount of irrigation is calculated with following equation and added to the rainfall:

$$Irrigation = MAX(\, 0, field\ capacity_{rootzone} - actual\ soil\ moisture_{rootzone}).$$

3.4.2 Scenario 2: Climate change

In the future higher temperatures due to climate change will have influence on the soil moisture. Through higher temperature, the evapotranspiration will rise and the soil moisture will decrease. It is assumed that the temperature will rise with circa 2°C in future. But to see the effect of temperature rise better, the influence of temperature rise is simulated by adding 5°C to all temperature maps. After changing the temperature maps, three runs are executed with the new climate data: no irrigation, fixed irrigation and scheduled irrigation.

3.4.3 Scenario 3: Dry and wet seasons

Another effect of climate change are extreme dry and wet seasons. To simulate a dry season, the rainfall data is changed, by setting all values to zero for one month (23-05-2013 to 23-06-2013) during growing season. Normally the wet seasons are during winter time. But for making a better comparison between dry and wet seasons, the wet season is also simulated during the same period, by changing the original values to values between 10 and 22mm (which are similar to the original maximum values of the whole year). Two runs are executed per rainfall event: no irrigation and scheduled irrigation. In total four runs are executed.

4 Model results

Within this chapter the results of the different calibration steps are described and compared to measured data. Most important model output is the water content in the root zone, because the modeled values can be compared with the values, measured by the DACOM soil moisture sensors (see Figure 3-1 for locations DACOM sensors).

In the first paragraph two different root depths are compared and in the second paragraph the influence of seepage is analyzed. Paragraph three describes the results of model runs with different amounts of irrigation and in paragraph four the differences are analyzed between static en dynamic crop factors.

4.1 Root depth 400mm vs. 600mm

The DACOM sensors measure the soil moisture up to 600mm depth. Therefore 600mm is chosen first as root depth within the SPHY-model. Another model run is executed with a root depth of 400mm. Both runs were executed without irrigation. To compare the model results of 400mm root depth with the DACOM values, only the first 400mm of the DACOM values are summed up.

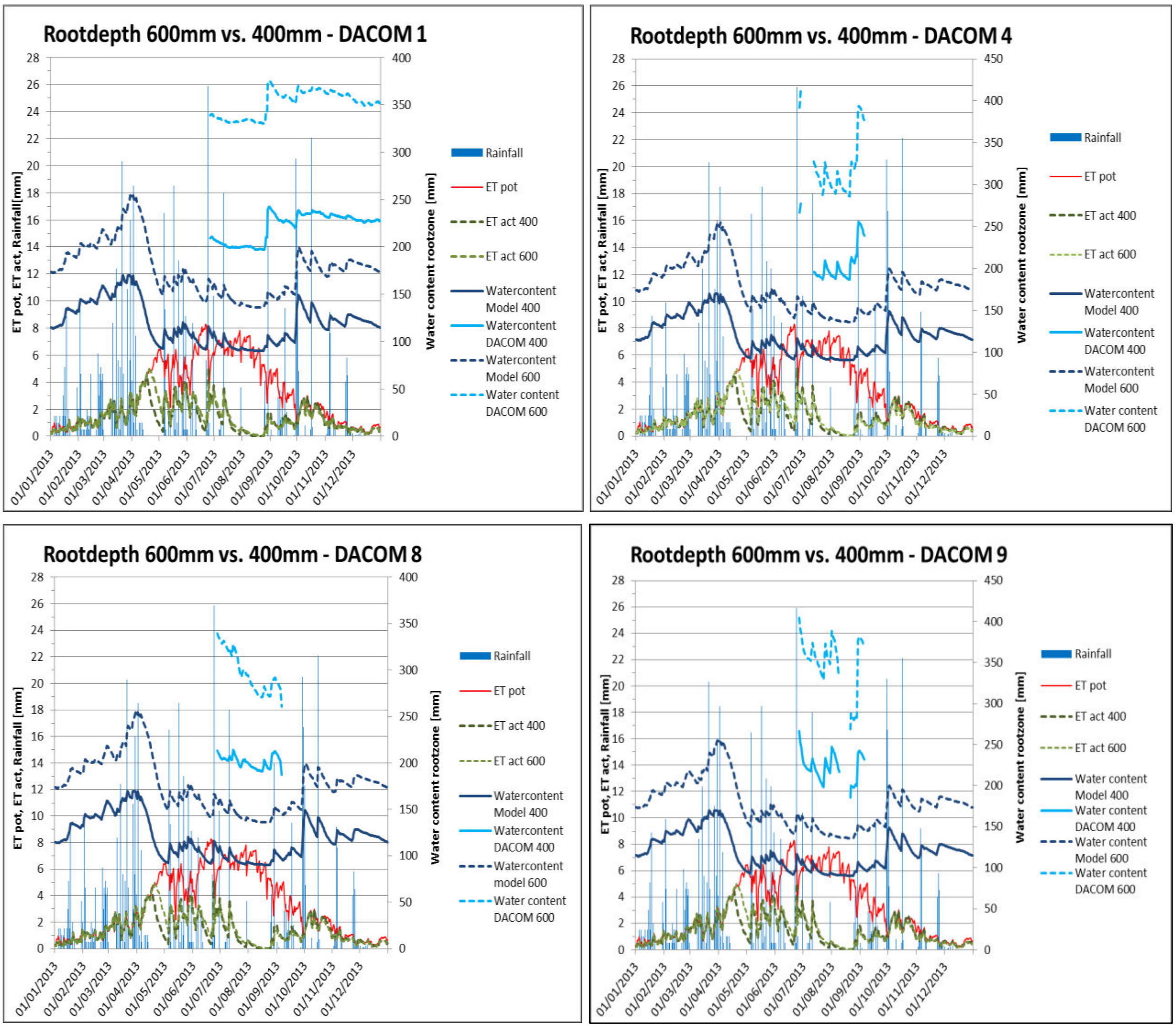


Figure 4-1: Model results root depth 400mm vs. 600mm for four different locations

In Figure 4-1 the results of the two runs are shown for four locations. The four points are chosen to look at in detail, because for this points many days of measured data are available. In the beginning and at the end of the year the actual evapotranspiration (ETact) is the same like the potential evapotranspiration (ETpot). Between half April and begin October the potential evapotranspiration increase, because temperature gets higher in the summer months. But actually the difference with actual evapotranspiration increases as well, because there is less water available for evapotranspiration in the dry summer months. Also the actual evapotranspiration of the model run with a root depth of 400mm is smaller than the evapotranspiration of the run with 600mm. This is because there is less water available for a smaller root depth, which can evaporate more quickly.

Next to differences in evapotranspiration there are also differences in root zone and subsoil drainage and in root zone percolation (see Table 4-1). The results of the run with 400mm root depth are higher than the values of the three parameters, calculated with a root depth of 600mm. The higher percolation and drainage is based on less space for water in a smaller root zone.

Table 4-1: Year results with 400mm and 600mm root depth - DACOM 4

Root depth	Capillary rise	ET act	ET pot	Precipitation	Rain Runoff	Root zone drainage	Root zone percolation
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
600 mm	0.00	526.91	1169.31	556.90	16.88	16.88	13.07
400 mm	0.00	501.19	1169.31	556.90	41.06	41.06	14.53

water content root zone	subsoil drainag e	water content subsoil	Total runoff	water content root zone begin	water content subsoil begin	water balance: precipitation + irrigation - total runoff + Δ water content - ET act
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
31-12-2013		*31-12-2013*		*1/1/2013*	*1/1/2013*	
173.47	11.84	642.06	28.72	173.65	640.84	0.24
114.72	14.29	641.95	55.36	114.83	641.72	0.23

The water content within the root zone (soil moisture) increase after heavy rainfall, e.g. in April, when the soil moisture is on its highest (see Figure 4-1). In the summer months the water content decreases because of less rainfall and higher temperatures. The average difference between the water content in a root zone of 600mm and a root zone of 400mm is ca. 60mm. The modeled water content is nearly the same at all locations. This is because all locations have the same soil types, the same climate data and the same crop factors within the model. Another reason is the small surface runoff, based on the plane grounds.

The water content measured by the DACOM sensors are different at each location, because the soil types, crop factors and climate data per location could be different in reality. Furthermore there are big differences between the modeled and measured water contents. The average difference between the modeled and measured water content is 110mm respectively 188mm for location one, 112mm resp. 178mm for location four, 106mm resp. 153mm for location eight and 126mm resp. 206mm for location nine.

First reason for the differences is, that irrigation is not simulated within these runs. So the amount of water coming from irrigation is missing. Point four and nine seems to be irrigated areas, because the DACOM values not strictly follow the rainfall pattern and have values above the measured values of point one and eight. Point one and eight follow the rainfall pattern and are probably non irrigated locations. So there have to be other reasons as well for the differences in measured and modeled water content.

Another reason for the differences could be the soil type used in the model. The field capacity and saturated water content of the soil type, used in the model are 170mm and 200mm for a root depth of 400mm, respectively 255mm and 300mm for a root depth of 600mm. Some values of the soil moisture measured by DACOM are higher than the saturated water content. Therefore the model results can be never the same as the DACOM values. However, there can be tried to get the results as similar as possible to the DACOM values.

Another possible reason for the differences, which should not be forgotten, could be wrong or too high measurements of the sensors, because of different incidents. Therefore research is done whether there is a linear relationship between measured and simulated values, by calculating the coefficient of determination (R^2) (see Figure 4-2). The R^2 value can be any number between zero and one. If the R^2 value is close to one, there could be a linear relationship between measured and modeled values, if the R^2 value is close to zero there is no linear relationship. The locations which seems to be non-irrigated (e.g. DACOM 1 or DACOM 5) have high R^2-values (see Table 4-2). This means that there is an absolute difference between the measured and modeled values, but that they have a similar distribution. Locations which are probably irrigated (e.g. DACOM 9) have a small R^2 value, because the distribution is not the same due to the missing irrigation in the model.

Because the absolute differences between measured and modeled data are bigger with a root depth of 600mm, there is chosen for a root depth of 400mm for the following runs.

Table 4-2: R^2 of the run with 400mm root depth

DACOM sensor	400mm root depth R^2
1	0.60
4	0.51
5	0.85
6	0.13
7	0.49
8	0.51
9	0.28
10	0.59

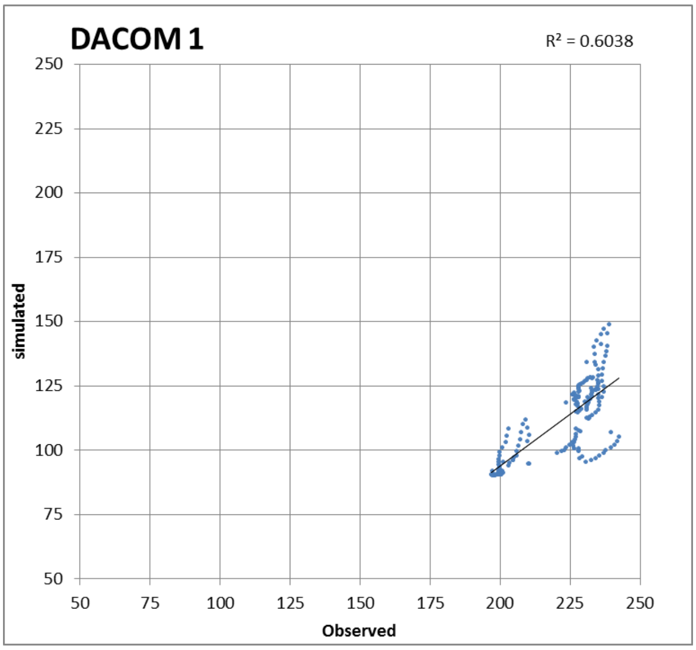


Figure 4-2: Statistical plot to calculate R2 - DACOM 1

4.2 Seepage

After choosing 400mm as root depth, another model run is executed, in which the seepage is changed from no seepage to -1,5mm. This means that 1,5mm/day is coming into the sub soil from the ground water. This run is executed to see if this will also influence the water content in the root zone. In the figure below the water content of the run with seepage is compared to the run without seepage and the water content measured by the DACOM sensors. There is nearly no difference in water content between the two runs. However, there is a big difference in subsoil drainage. The difference in subsoil drainage between the two runs is nearly 500mm (see Table 4-3). Because of the barely recognizable difference in water content of the root zone, there is chosen not to use seepage in the following runs.

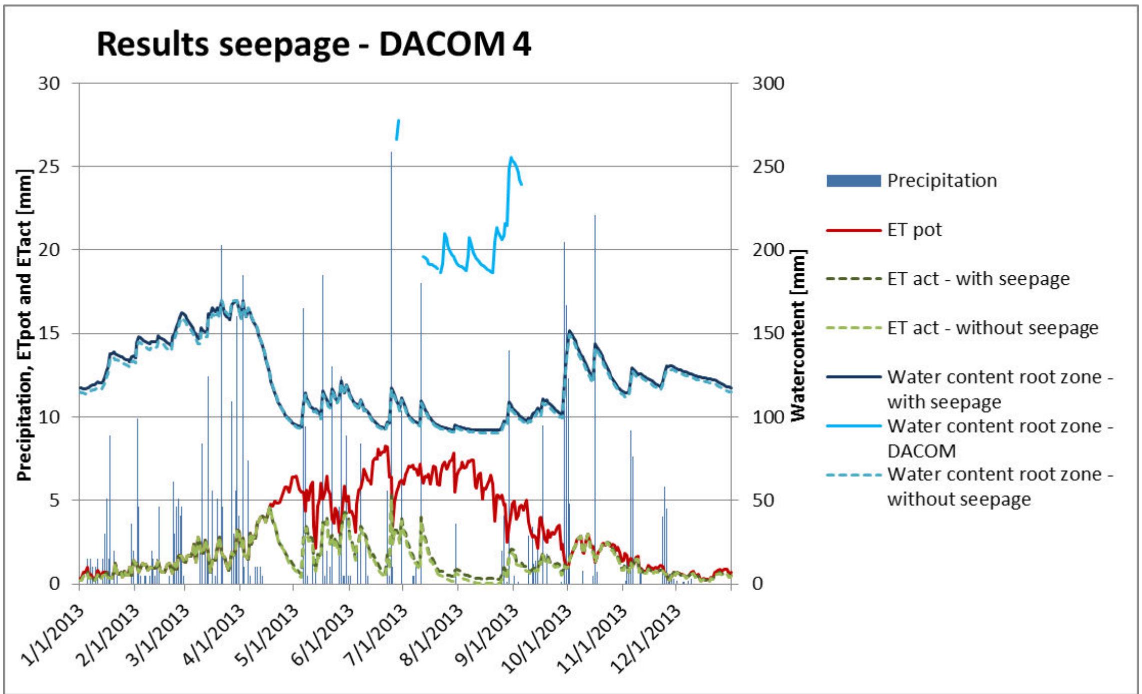


Figure 4-3: Results with and without seepage - DACOM 4

Table 4-3: Year results with and without seepage - DACOM 4

Seepage	Capillary rise	ET act	ET pot	Precipitation	Rain Runoff	Root zone drainage	Root zone percolation
mm/day	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
-1.5	41.74	539.14	1169.31	556.9	42.72	42.72	16.64
0	0	501.19	1169.31	556.9	41.06	41.06	14.53

Seepage	water content root zone	subsoil drainage	water content subsoil	Total runoff	water content root zone begin	water content subsoil begin	water balance: precipitation - total runoff + Δ water content - ET act - seepage
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
	31-12-13		*31-12-13*		*01-01-13*	*01-01-13*	
-546	117.36	520.89	651.17	563.61	117.48	651.16	0.26
0	114.7	14.29	641.95	55.36	114.83	641.72	0.23

4.3 Irrigation

To get results which are more similar to the DACOM values, irrigation has to be modeled as well. To simulate irrigation, first a model run is executed with the difference between the potential and actual evapotranspiration added to the precipitation as irrigation. This results in an average increase in water content of 8mm (see Figure 4-4) The difference between potential and actual evapotranspiration becomes smaller. Actually the difference between potential and actual evapotranspiration is still large. This means that the added amount of water is not enough to realize that the actual evapotranspiration is the same as the potential evapotranspiration. Therefore four other model runs are executed, in which the amount of irrigation water is multiplied by two, five, ten and twenty. Figure 4-4 shows the results of all runs.

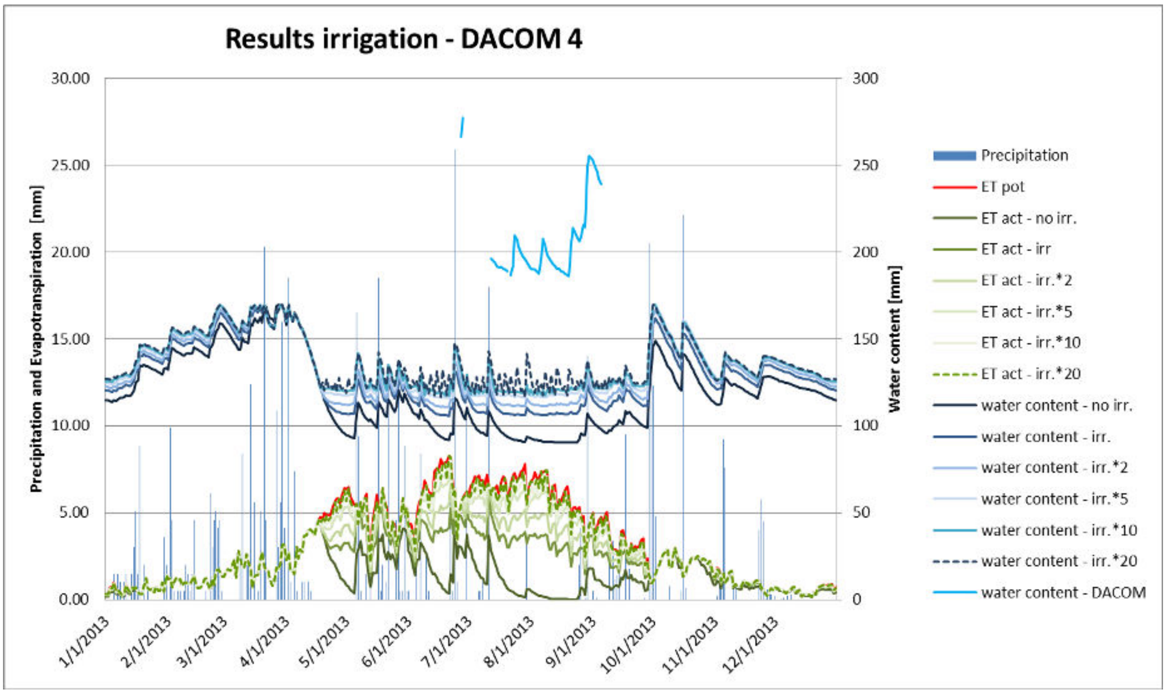


Figure 4-4: Results irrigation - DACOM 4

The water content increases from run to run, but the increase becomes smaller. Also the root zone and sub soil drainage and the root zone percolation increases from run to run (see Table 4-4). The difference between potential and actual evapotranspiration decreases. At irrigation factor 20, the actual and potential evapotranspiration are nearly the same, with a maximum difference of 1.35mm. This means, that with this calculation method for irrigation, the maximum water content is nearly reached.

Table 4-4: Year results with and without irrigation - DACOM 4

Irrigation pattern	Capillary rise	ET act	ET pot	Precipitation	Irrigation	Rain Runoff	Root zone drainage
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
No irrigation	0.00	501.19	1169.31	556.90	0.00	41.06	41.06
ET pot - ET act	0.00	832.15	1169.31	556.90	337.18	43.08	43.08
(ET pot - ET act)*2	0.00	943.83	1169.31	556.90	450.99	43.55	43.55
(ET pot - ET act)*5	0.00	1055.69	1169.31	556.90	568.15	45.89	45.89
(ET pot - ET act)*10	0.00	1106.87	1169.31	556.90	624.49	49.29	49.29
(ET pot -ET act)*20	0.00	1136.45	1169.31	556.90	657.17	51.52	51.52

Root zone percolation	water content root zone	subsoil drainage	water content subsoil	Total runoff	water content root zone begin	water content subsoil begin	water balance: precipitation + irrigation - total runoff + Δ water content - ET act
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
	31-12-2013		*31-12-2013*		*1/1/2013*	*1/1/2013*	
14.5266	114.72	14.29	641.95	55.36	114.83	641.72	0.23
18.7655	120.28	18.83	641.66	61.91	120.51	641.72	0.31
20.4375	122.39	20.63	641.53	64.18	122.67	641.72	0.35
23.3485	124.35	23.74	643.14	69.62	124.62	643.53	0.39
25.0749	125.64	25.01	643.74	74.30	125.92	643.67	0.44
25.9719	126.89	25.91	643.66	77.43	127.23	643.59	0.47

Although the absolute difference in water content to the measured DACOM values becomes smaller by using irrigation, the R^2 values become smaller. This means that there is no linear relationship between measured and modeled values. Reason for this could be the irrigation pattern. If another irrigation pattern is used in reality than in the model, there can be no linear relationship.

Table 4-5: R^2 of the run with irrigation=(ET pot - ET act)*20

DACOM sensor	No irrigation R^2	Irrigation*20 R^2
1	0.60	0.32
4	0.51	0.04
5	0.85	0.28
6	0.13	0.09
7	0.49	0.03
8	0.51	0.06
9	0.28	0.08
10	0.59	0.03

4.4 Static vs. dynamic crop factors

The previous runs are executed with static crop factors, so there is no change in vegetation through the year (see Table 4-6). The crop factors of the agricultural areas are average values of the planted crops during midseason. Actually, plants have varying sizes and crop factors during a year. Therefore new runs are executed with dynamic crop factors and are compared with the results of static crop factors.

Table 4-6: Static crop factors

Land use class	Crop factor
Irrigated agriculture	1.15
Non-irrigated agriculture	1.15
Bare soil	1
Urban areas	1
Nature	0.95
Water	1.05

The dynamic crop factors are determined based on the crop factors given by FAO (source (FAO, 1998)), by taking the average of the crop factors per season. A schematic diagram of the dynamic crop factors during growing season can be found in Figure 4-5. Before planting and after harvesting, the agricultural areas will have the same crop factor as bare soil. Bare soil, urban areas, nature and water will have no dynamic crop factors.

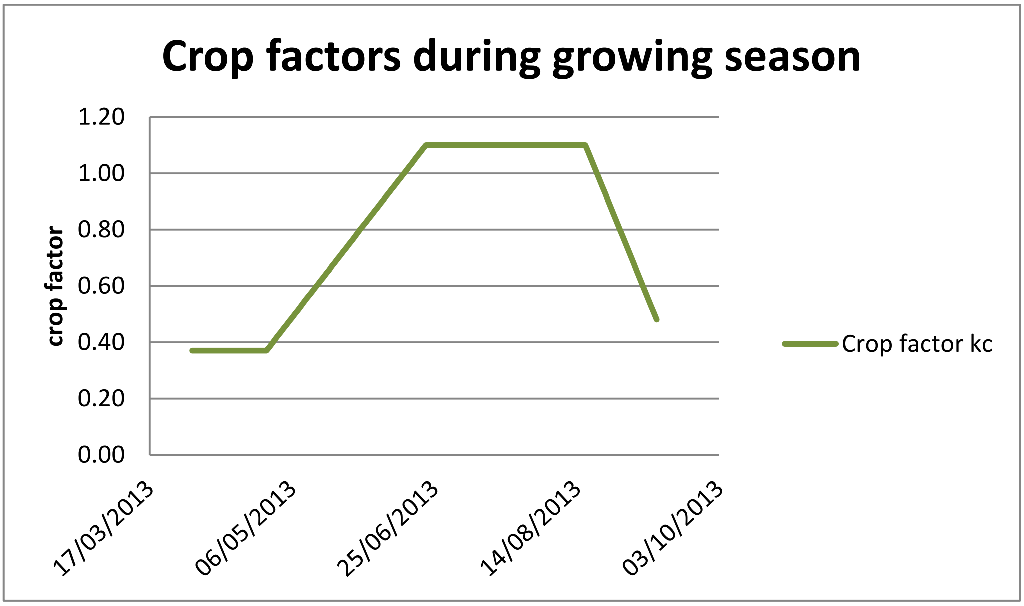


Figure 4-5: Dynamic crop factors

In Figure 4-6 the results of the runs with static crop factors are compared with the runs with dynamic crop factors. In the begin of the growing season, the water content calculated with dynamic crop factors is higher than the water content calculated with static crop factors. The reason of this difference is, that the evapotranspiration is lower based on the smaller dynamic crop factors in the begin of the growing season. When the dynamic crop factors reach their top (end of June), the crop factor is the same than the static crop factor. At this point the water content of the root zone and the evapotranspiration become the same in both runs.

The runs executed with irrigation show smaller difference, but also less water is needed for irrigation. Less water is needed because even without irrigation the water content of the run with dynamic crop factors is most of the time higher than the water content of the run with static crop factors. Also drainage in subsoil and root zone and root zone percolation are higher in dynamic runs than the results of the runs with static crop factors (see Table 4-7). This is because more water is available due to the smaller evapotranspiration.

Table 4-7:Year results with dynamic and static crop factors - DACOM 4

Run	Capillary rise	ET act	ET pot	Precipitation	Irrigation	Rain Runoff	Root zone drainage
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
No irrigation static	0.00	501.19	1169.31	556.90	0.00	41.06	41.06
No irrigation dynamic	0.00	472.20	906.89	556.90	0.00	60.41	60.41
Irrigation static	0.00	832.15	1169.31	556.90	337.18	43.08	43.08
Irrigation dynamic	0.00	686.06	906.89	556.90	220.83	66.38	66.38
Irrigation * 20 static	0.00	1136.45	1169.31	556.90	657.17	51.52	51.52
Irrigation * 20 dynamic	0.00	885.19	906.89	556.90	433.92	76.94	76.94

Root zone percolation	water content root zone	subsoil drainage	water content subsoil	Total runoff	water content root zone begin	water content subsoil begin	water balance: precipitation + irrigation - total runoff + Δ water content - ET act
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
	31-12-2013		*31-12-2013*		*1/1/2013*	*1/1/2013*	
14.53	114.72	14.29	641.95	55.36	114.83	641.72	0.23
24.47	121.34	24.57	641.26	84.98	121.78	641.36	0.26
18.77	120.28	18.83	641.66	61.91	120.51	641.72	0.31
25.89	129.35	26.05	641.20	92.43	130.27	641.36	0.32
25.9719	126.89	25.91	643.66	77.43	127.23	643.59	0.47
29.1	132.76	29.07	643.64	106.02	133.492	643.11	0.32

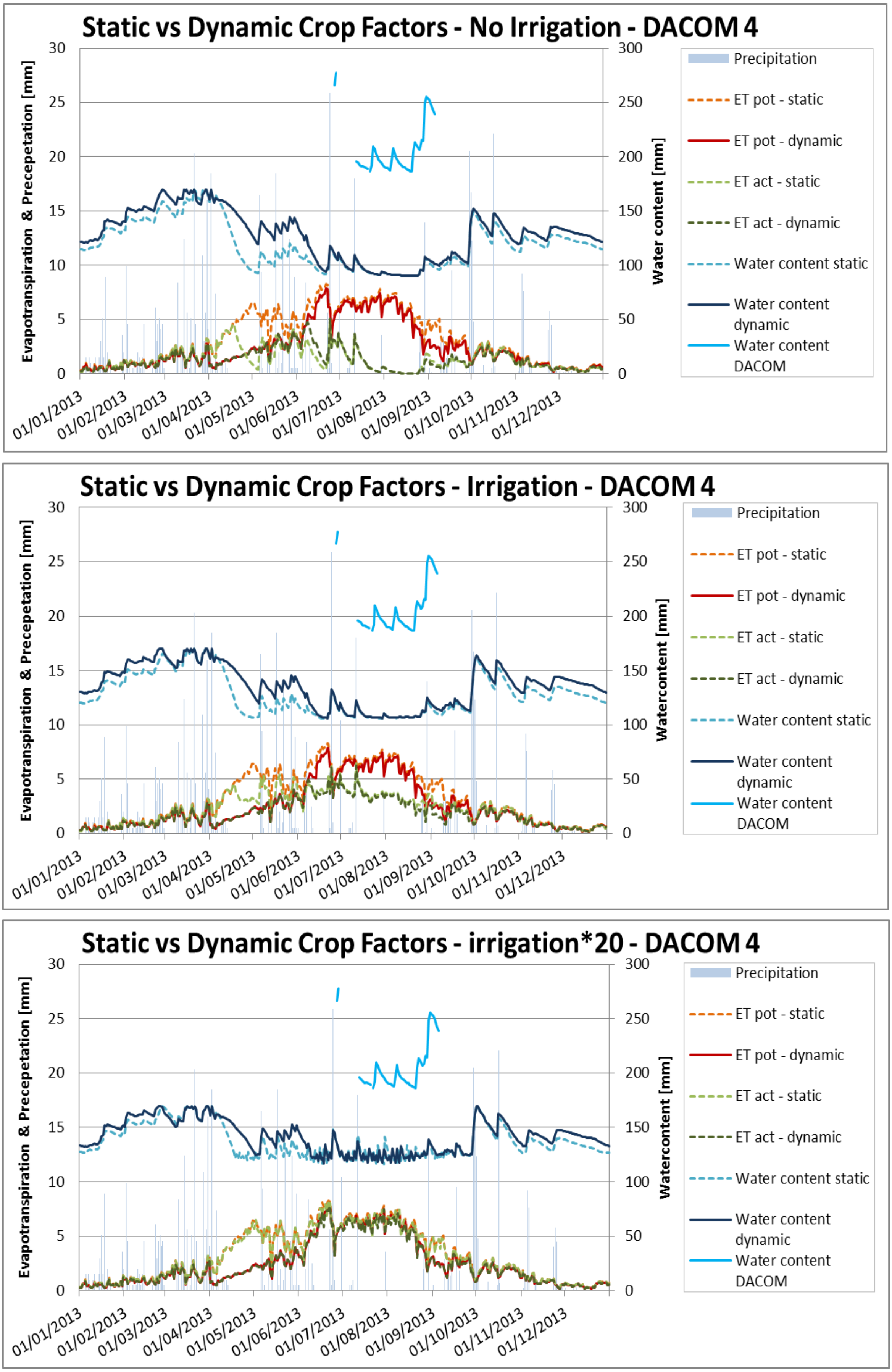


Figure 4-6: Static vs. dynamic crop factors

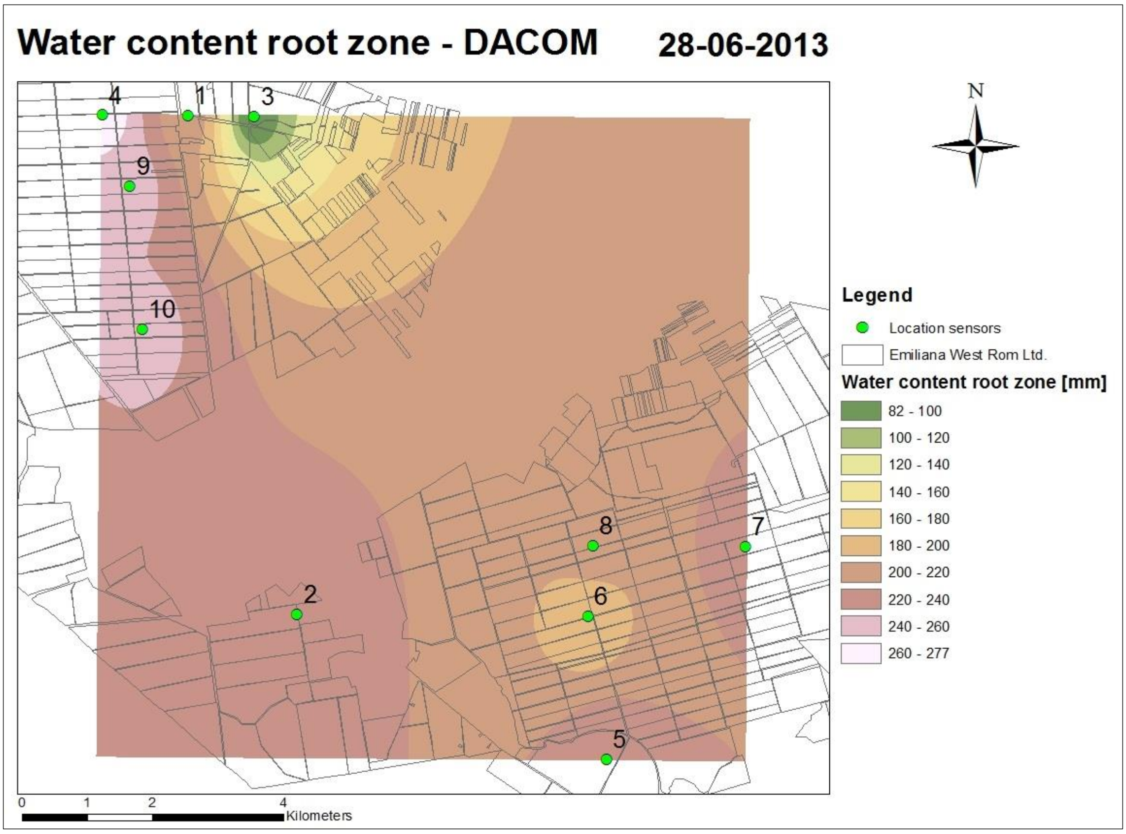
The results of the runs with dynamic crop factors follow the growing season much better and the water content is higher most of the time, due to small evapotranspiration during the begin of the growing season. Actually the results still differs a lot from the DACOM values, but the R^2 values become larger compared to the runs with static crop factors (see Table 4-8). So the difference in distribution becomes smaller with dynamic crop factors.

Table 4-8: R^2 of static and dynamic runs with and without irrigation

DACOM sensor	No irrigation static R^2	No irrigation dynamic R^2	Irrigation static R^2	Irrigation dynamic R^2
1	0.60	0.66	0.32	0.50
4	0.51	0.57	0.04	0.29
5	0.85	0.87	0.28	0.05
6	0.13	0.16	0.09	0.12
7	0.49	0.51	0.03	0.07
8	0.51	0.49	0.06	0.11
9	0.28	0.30	0.08	0.18
10	0.59	0.64	0.03	0.20

Because the results of the run with dynamic crop factors and irrigation have the smallest absolute difference with measured values, the results will also compared based on water content maps (see Figure 4-7). Figure 4-7 shows the water content in the root zone on 28th June 2013, measured by the DACOM sensors and of a model run with dynamic crop factors and irrigation (irrigation = $(ET_{pot}-ET_{act})*20$). The lowest and highest values, measured by DACOM are 82mm and 277mm, the lowest and highest values calculated by the model are 87 and 200mm.

Also the values of DACOM differs more between the different sensors, compared to the model results. The results of the model are nearly the same at all calibration points. The reason of the bigger differences between the DACOM sensors are probably different soil types and different crop factors. In the model the soil type and crop factor of every location is the same. Therefore there are nearly no differences between the different calibration points. The influence of the soil type on the water content is very big. This become good visible on the water content maps of the model, because the biggest differences in water content are between areas with different soil types, based on a different saturated hydraulic conductivity (ksat) per soil type.



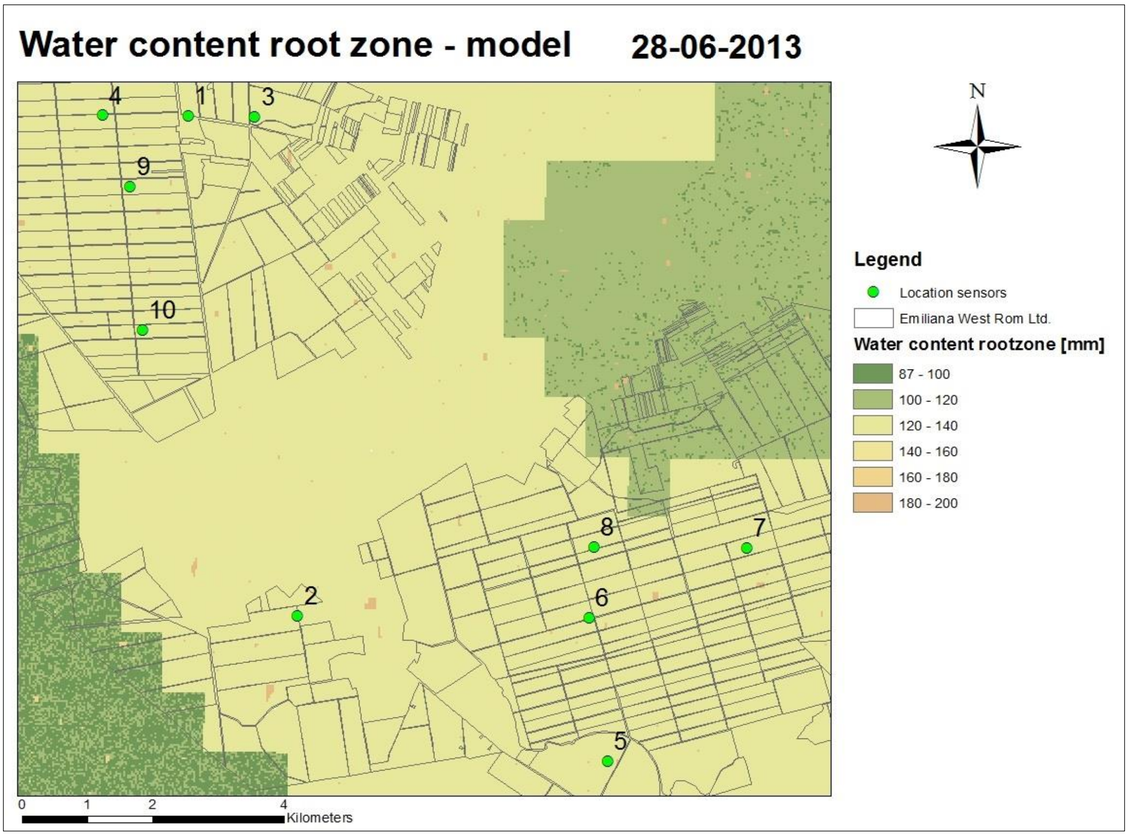
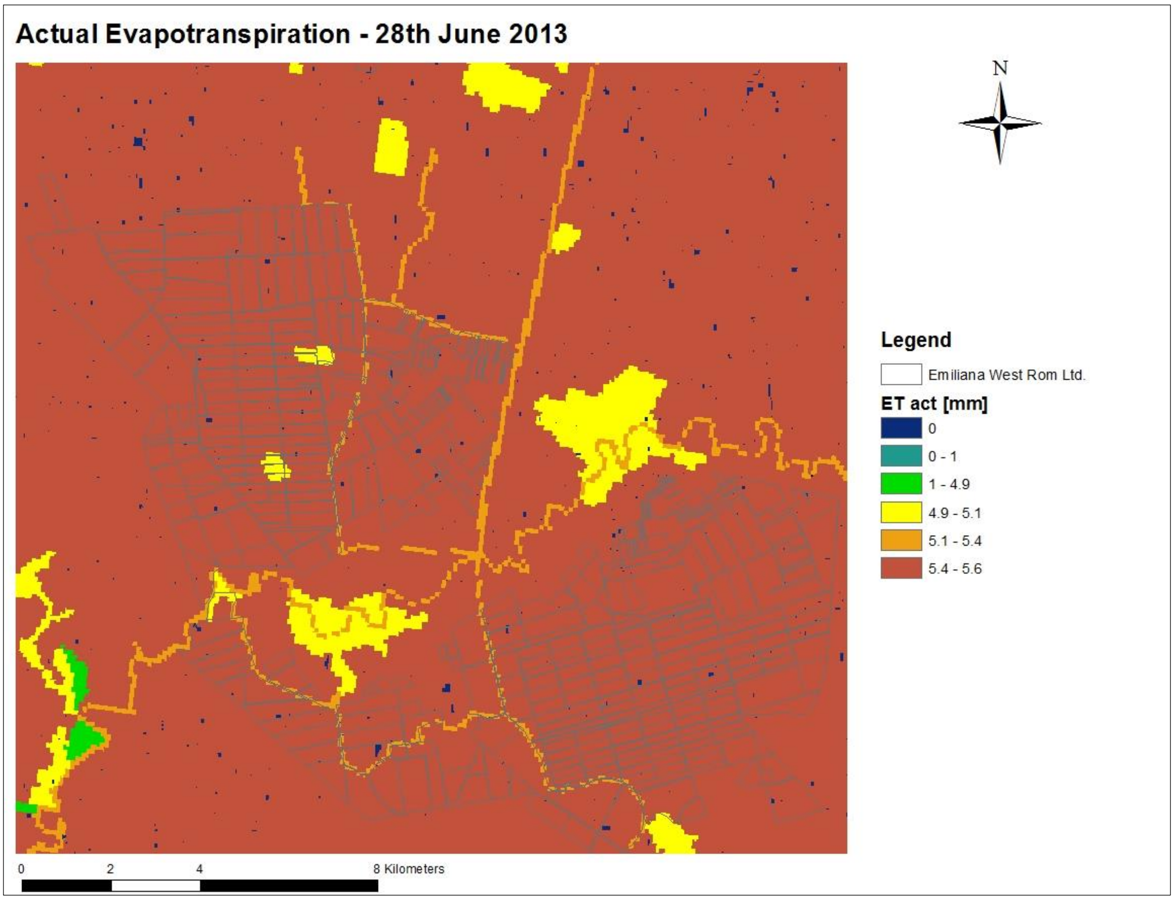


Figure 4-7: Water content root zone - DACOM vs. Model, 28th June 2013

In Figure 4-8 the actual evapotranspiration of 28th June and the total evapotranspiration of 2013 are compared. Both are calculated with SPHY. In both maps the influence of the different crop factors become visible. Urban areas, water, bare soil and nature are silhouetted against the agricultural areas (irrigated and non-irrigated). Between irrigated and non-irrigated agricultural areas there are no differences, because of the same crop factors and because no difference is made between different land use classes when simulating irrigation. Irrigation is added to rainfall. Therefore all areas got irrigation water in the model.

On 28th June agriculture has the highest evapotranspiration due to the high crop factors during mid-season. The second highest evapotranspiration takes place in open water areas, followed by the urban areas. On year basis the evapotranspiration of the agricultural areas is lower than the evapotranspiration in other areas. The reason for the low evapotranspiration on year basis are the small crop factors of the agricultural areas in the begin of the growing season.

Though there are big differences in water content between model results and measured values, these results are the best possible, looking at the global data (soil data) and the used method to simulate irrigation. Therefore these results will be used as definitive results, with which the results of the scenarios will be compared.



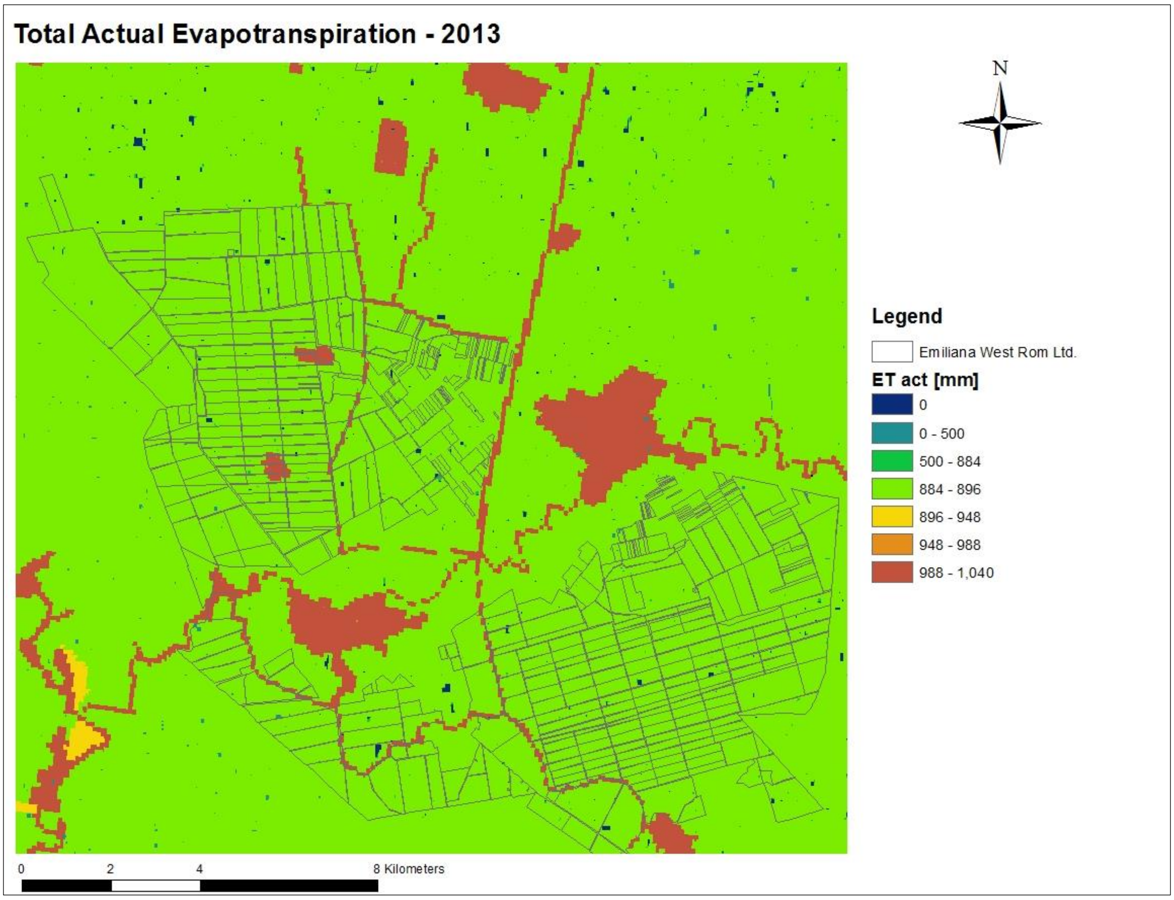


Figure 4-8: Actual Evapotranspiration

5 Optimization of agricultural water resource management

Within this chapter the results of the different scenarios are described and analyzed. By analyzing the results, advice can be given on how to improve the agricultural water resource management by using SPHY.

5.1 Scenario 1: Fixed vs. scheduled irrigation

Within this scenario different irrigation patterns are analyzed. The irrigation method of chapter four (irrigation = $(ET_{pot} - ET_{act})*20$) is compared with an irrigation pattern independent and an irrigation pattern dependent on climate and actual soil moisture (see Figure 5-1). The fixed irrigation pattern includes an irrigation of 18mm once a week during the growing season. The amount of irrigation water of the scheduled irrigation pattern is the difference between field capacity and actual soil moisture.

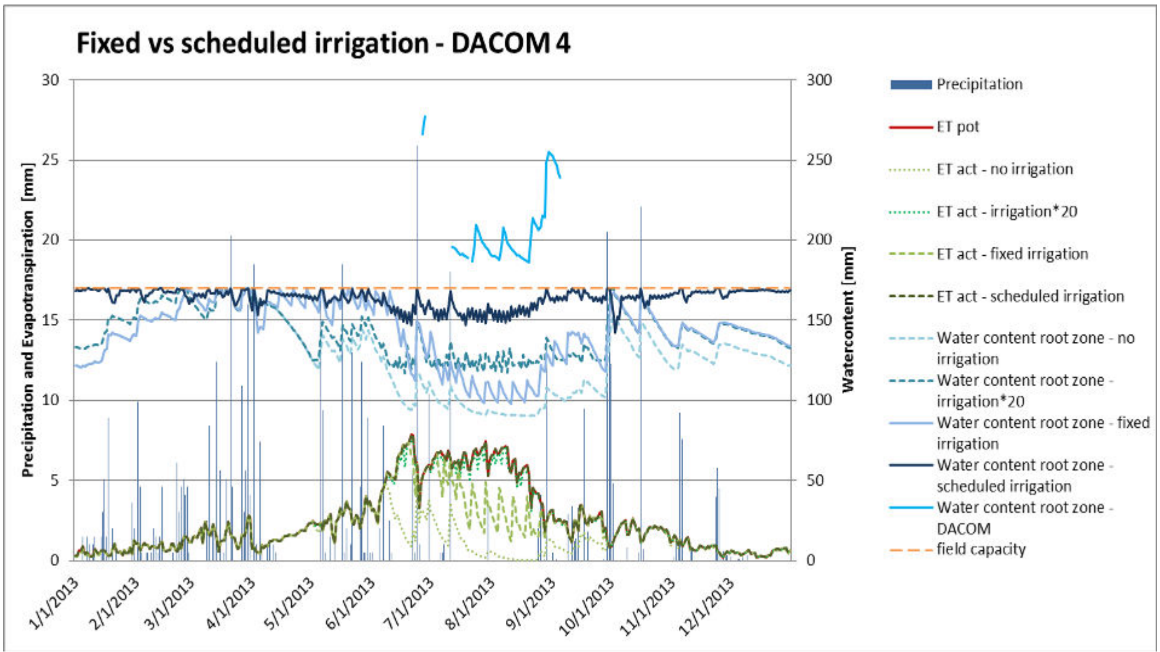


Figure 5-1: Results scenario 1: Scheduled vs. fixed irrigation

During the whole time the water content of the run with scheduled irrigation is at field capacity (170m) or little below it. In the begin of the growing season the water content of the run with fixed irrigation is around field capacity as well, because of the big amount of rainfall. The rest of the growing season the water content is far below field capacity and from July till September even below the wilting point (129mm). The reason for the low water content is less rainfall. Also the actual evapotranspiration is lower than the potential evapotranspiration within these months. So for months with little rainfall the fixed irrigation pattern is not suitable. The run with the irrigation pattern dependent of the difference between potential and actual evapotranspiration is below field capacity during the whole season. With this irrigation pattern the water content could not get any higher, because the difference between potential and actual evapotranspiration is already nearly zero.

The different irrigation patterns result in different amounts of irrigation water during one season (see Table 5-1). The fixed irrigation and the irrigation based on the difference of potential and actual evapotranspiration have an amount of irrigation water of ca. 400mm. The amount of water of the scheduled irrigation is higher (566mm). This results in a difference of ca. 4 M m^3 in one season.

Table 5-1: Amount of irrigation water during growing season

	1st April - 11th September	
	Total irrigation [mm]	Total irrigation [M m3]
*Irrigation*20*	412	12.36
Fixed irrigation	432	12.96
Scheduled irrigation	566	16.98

Also the amount of total runoff is different between the different irrigation patterns (see Table 5-2). Though the fixed irrigation pattern and the irrigation pattern dependent on evapotranspiration deficit have nearly the same amount of irrigation water, the total runoff of the fixed irrigation pattern is two times higher. This means that irrigation is applied on days, when it is not needed. The total runoff of the scheduled irrigation pattern is the highest, due to the highest amount of irrigation water.

Table 5-2: Year results scenario 1 - DACOM 4

Run	Capillary rise	ET act	ET pot	Precipitation	Irrigation	Rain Runoff	Root zone drainage
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
No irrigation	0.00	472.20	906.89	556.90	0.00	60.41	60.41
Irrigation * 20	0.00	885.19	906.89	556.90	433.92	76.94	76.94
Fixed irrigation	0.00	750.02	906.89	556.90	432.00	158.38	158.38
Scheduled irrigation	0.00	906.89	906.89	556.90	789.50	323.60	323.60

Root zone percolation	water content root zone	subsoil drainage	water content subsoil	Total runoff	water content root zone begin	water content subsoil begin	water balance: precipitation + irrigation - total runoff + Δ water content - ET act
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
	31-12-2013		*31-12-2013*		*1/1/2013*	*1/1/2013*	
24.47	121.34	24.57	641.26	84.98	121.78	641.36	0.26
29.1	132.76	29.07	643.64	106.02	133.492	643.11	0.32
68.33	133.58	68.62	641.06	227.01	121.78	641.36	0.37
116.83	168.52	116.82	643.19	440.43	168.23	643.19	-1.2

Not only the difference in amount of water is important, but also the difference in crop yield. The crop yield is better as smaller the difference between actual and potential evapotranspiration is. The crop yield is at is best with the scheduled irrigation (ET_{act} / ET_{pot}=1, see Table 5-3). Furthermore the relationship between crop yield and amount of irrigation is calculated. Aim is a small value. The irrigation pattern, dependent on evapotranspiration, has the smallest value. The values of fixed and scheduled irrigation hardly differ from each other. So there could be said that the irrigation pattern, dependent on evapotranspiration is the best choice.

Table 5-3: Relationship between crop yield and amount of irrigation

Irrigation pattern	Amount of irrigation [mm]	ET act [mm]	ET pot [mm]	ET act / ET pot	Irrigation/(Etact/Etpot)
Irrigation *20	412	649.52	670.08	0.97	425.04
Fixed irrigation	432	516.09	670.08	0.77	560.90
Scheduled irrigation	566	670.08	670.08	1	566.00

But though the irrigation pattern dependent on evapotranspiration has the smallest value and the scheduled irrigation pattern needs the most irrigation water, the scheduled irrigation pattern is the most suitable one. The irrigation pattern, dependent on evapotranspiration, results in a soil moisture around the wilting point during summer months. Therefore the irrigation pattern, based on the evapotranspiration deficit, is less suitable. Furthermore the water content of the scheduled irrigation pattern stays at a steady level during the whole time.

5.2 Scenario 2: Climate change

In future temperature will rise due to climate change. Within this scenario a temperature rise of 5˚C is simulated. Normally it is assumed that the temperature will rise with ca. 2˚C in future, but to show a bigger effect, there is chosen to execute the run with a temperature rise of 5˚C. Figure 5-2 shows the results of three model runs with higher temperature: no irrigation, fixed irrigation and scheduled irrigation.

The potential evapotranspiration rises, up to a rise of 0.9mm/day. Because of the higher evapotranspiration the water content decreases. At the run with no irrigation the water content decreases by an average of 6mm. The maximum decrease is 20mm. There is no decrease in water content during the months July, August and September, because the water content is already around the wilting point. At this level, a quick decrease of the water content is not possible.

The run with fixed irrigation also results in no difference during July and August, because the water content is already very low (between wilting and permanent wilting point). In June and September the difference in water content amounts to several millimeters. The actual evapotranspiration increases with more than 50mm during one year (see Table 5-4) and the total runoff decreases.

Compared to the other irrigation patterns, there is nearly no difference in water content of the runs with scheduled irrigation, because the irrigation pattern adapt easily to higher temperatures, by using more irrigation water (see Table 5-4). Because the irrigation pattern easily adapt to new climate situations, there will be no damage in crop yield due to higher temperatures. This make this irrigation pattern very suitable for modern agricultural water resource management.

Table 5-4: Year results scenario 2 - DACOM 4

Run	Capillary rise	ET act	ET pot	Precipitation	Irrigation	Rain Runoff	Root zone drainage
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
No irrigation old temperature	0.00	472.20	906.89	556.90	0.00	60.41	60.41
No irrigation new temperature	0.00	501.69	1039.48	556.90	0.00	44.90	44.90
Fixed irrigation old temperature	0.00	750.02	906.89	556.90	432.00	158.38	158.38
Fixed irrigation new temperature	0.00	804.63	1039.48	556.90	432.00	136.02	136.02
Scheduled irrigation old temperature	0.00	906.89	906.89	556.90	789.50	323.60	323.60
Scheduled irrigation new temperature	0.00	1039.48	1039.48	556.90	876.57	287.97	287.97

Root zone percolation	water content root zone 31-12-2013	subsoil drainage	water content subsoil 31-12-2013	Total runoff	water content root zone begin 1-1-2013	water content subsoil begin 1-1-2013	water balance: precipitation + irrigation - total runoff + Δ water content - ET act
mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
24.47	121.34	24.57	641.26	84.98	121.78	641.36	0.26
10.17	113.35	9.33	642.43	54.22	113.43	641.58	0.22
68.33	133.58	68.62	641.06	227.01	121.78	641.36	0.37
46.04	115.38	46.58	641.19	182.60	113.43	641.73	0.26
116.83	168.52	116.82	643.19	440.43	168.23	643.19	-1.20
105.27	167.32	105.27	643.21	393.24	168.49	643.21	1.92

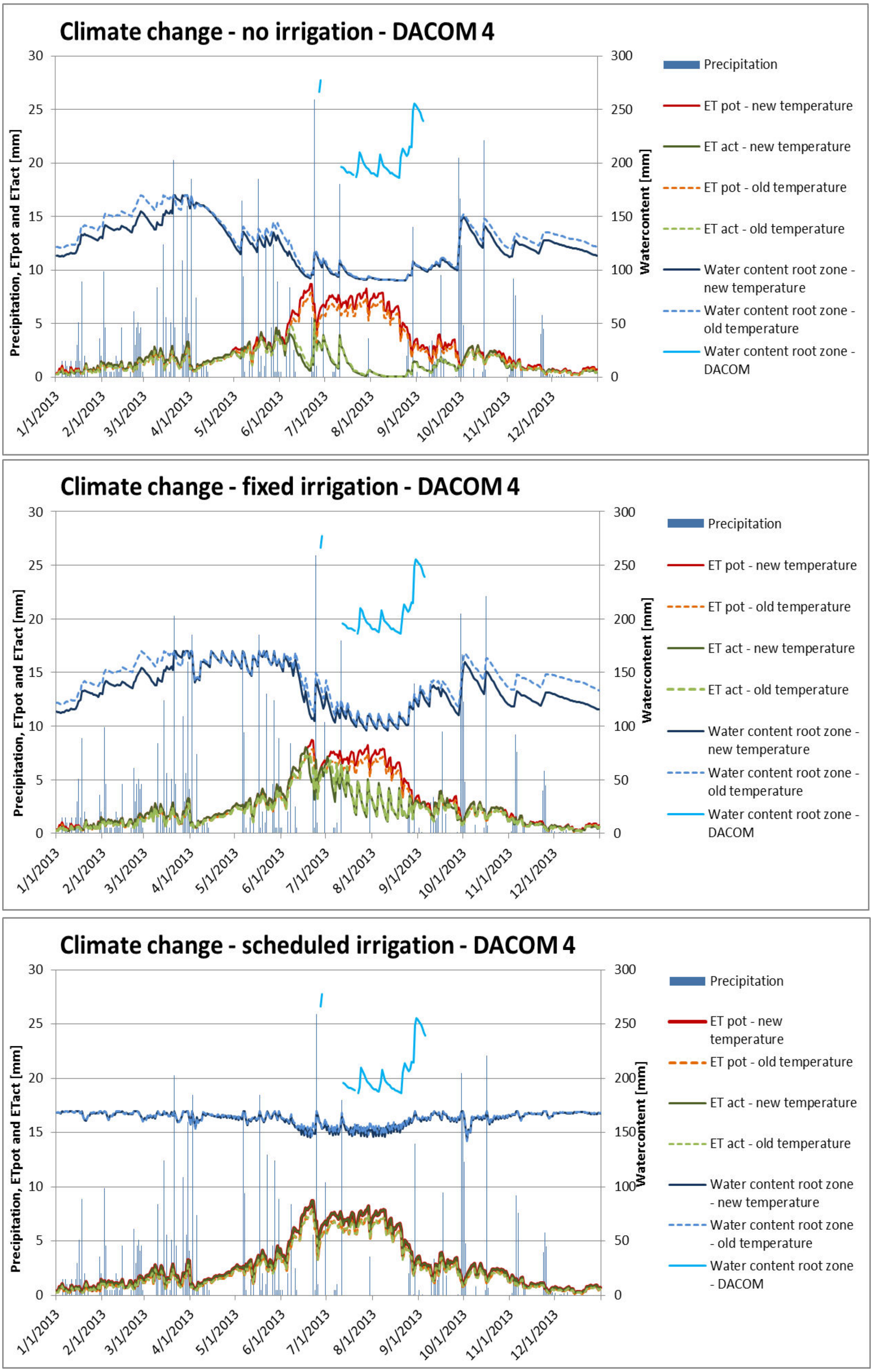


Figure 5-2: Results scenario 2: Climate change

5.3 Scenario 3: Dry and wet seasons

Another effect of climate change are extreme dry and extreme wet seasons. To simulate extreme dry and wet situations, the rainfall is changed during one month. The results are shown in the figure below.

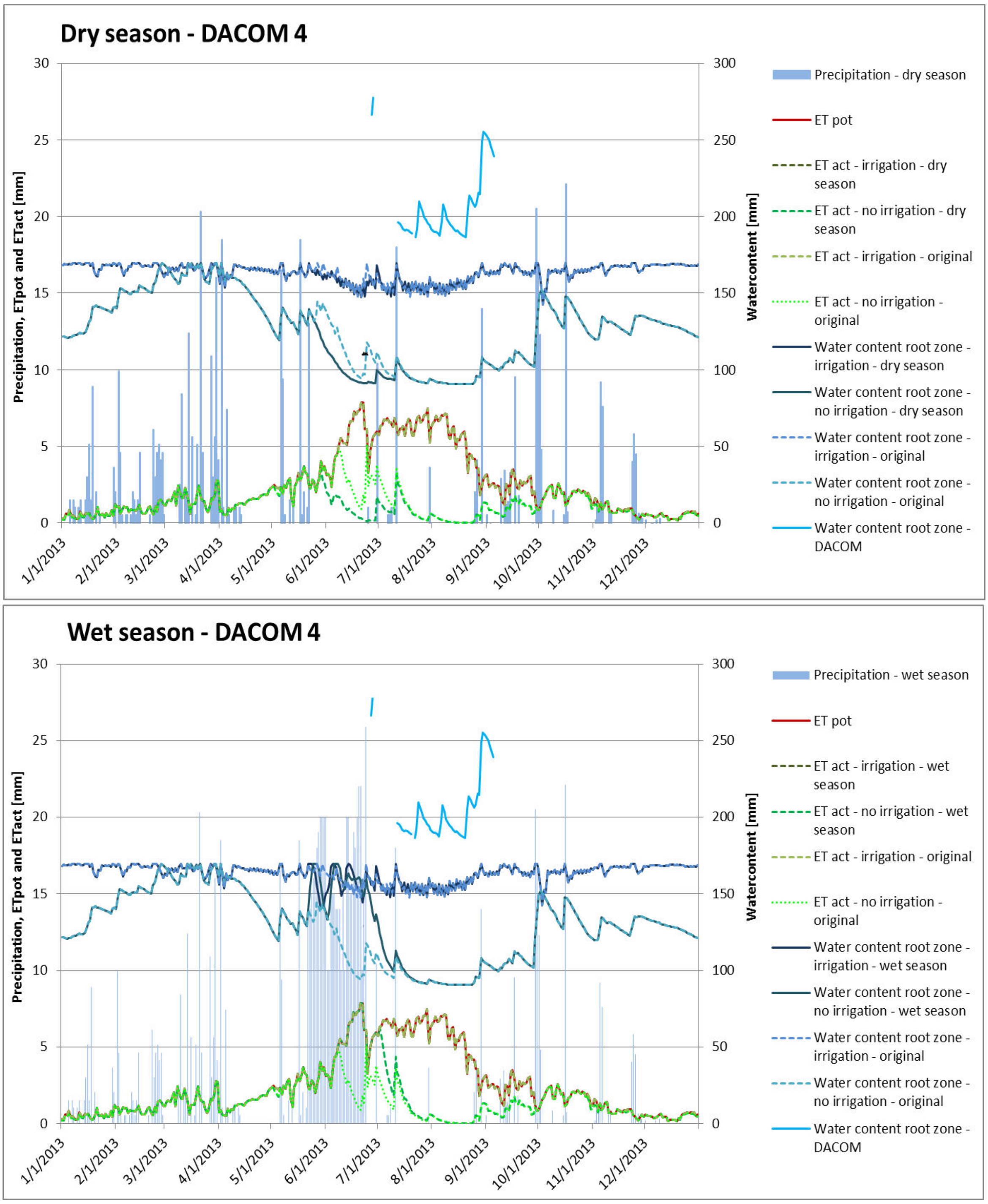


Figure 5-3: Results scenario 3: Dry and wet seasons

During the dry season the water content decreases with around 6mm/day, which results in a total amount of ca.600mm when no irrigation is applied. Furthermore the actual evapotranspiration decreases with a total amount of 73mm during the dry season. When the scheduled irrigation pattern, dependent on the actual soil moisture, is applied, there is nearly no decrease in water content and no decrease in actual evapotranspiration. The irrigation pattern adapt easily to the new situation by using more water for irrigation (see Table 5-5).

The water content increases with a total amount of 1653mm during wet season, when no irrigation is applied. Also the actual evapotranspiration increases with a total amount of 104mm. There is nearly no change in water content and no increase in actual evapotranspiration, when irrigation is applied, because less irrigation water is used (see Figure 5-4).

Figure 5-4 compares the amounts of irrigation in the three situations. At dry season the amount of irrigation water increases. The amount of irrigation during wet season is nearly zero. With the scheduled irrigation pattern, there will never be used more water than needed. This leads to a sustainable and responsible use of water. Also the crop yield will be improved, because the danger of wet or dry damage is smaller.

Table 5-5: Year results scenario 3 - DACOM 4

Run	Capillary rise	ET act	ET pot	Precipitation	Irrigation	Rain Runoff	Root zone drainage	Root zone percolation	water content root zone	subsoil drainage	water content subsoil	Total runoff	water content root zone begin	water content subsoil begin	water balance: precipitation + irrigation - total runoff + Δ water content - ET act
	mm	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
									31-12-2013		*31-12-2013*		*1/1/2013*	*1/1/2013*	
No irrigation original	0.00	472.20	906.89	556.90	0.00	60.41	60.41	24.47	121.34	24.57	641.26	84.98	121.78	641.36	0.26
Scheduled irrigation original	0.00	906.89	906.89	556.90	789.50	323.60	323.60	116.83	168.52	116.82	643.19	440.43	168.23	643.19	-1.20
No irrigation dry season	0.00	398.90	906.89	483.60	0.00	60.41	60.41	24.47	121.34	24.57	641.26	84.98	121.78	641.36	0.26
Scheduled irrigation dry season	0.00	906.89	906.89	483.60	841.09	312.31	312.31	106.40	168.52	106.40	643.19	418.71	168.23	643.19	-1.19
No irrigation wet season	0.00	573.86	906.89	1025.50	0.00	405.55	405.55	46.27	121.34	45.70	641.92	451.26	121.78	641.36	0.26
Scheduled irrigation wet season	0.00	906.89	906.89	1025.50	687.61	681.69	681.69	125.45	168.52	125.45	643.19	807.14	168.23	643.19	-1.20

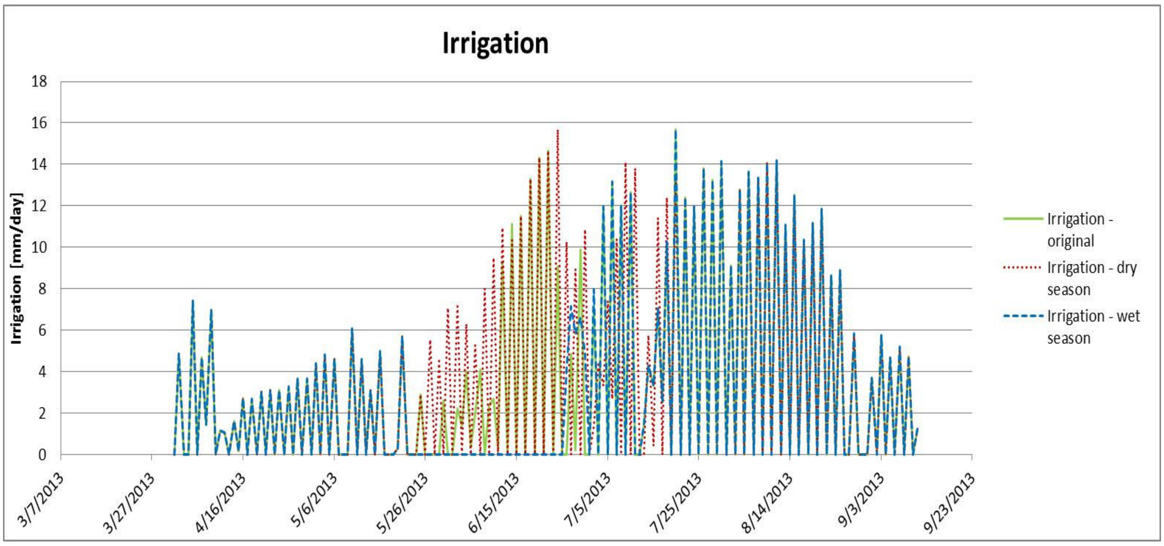


Figure 5-4: Amount of irrigation in different seasons

6 Conclusion, Discussion and Recommendations

Within this chapter the conclusion is given by answering the research questions. Furthermore advice and recommendations will be given in paragraph two, based on the discussion.

6.1 Conclusion

The main question of this research is:

How can the agricultural water resource management at the study site be optimized by using SPHY?

The agricultural water resource management at the study site can be optimized with SPHY, by calculating actual soil moisture and evapotranspiration. Based on the difference between field capacity and actual soil moisture, the optimal amount of irrigation can be determined. Because the irrigation pattern is dependent on actual circumstances, there will never be far too much or far too little water for plant growth. Also this irrigation pattern easily adapt to new circumstances due to climate change. This results in an optimal and sustainable use of irrigation water.

To come to this conclusion first the characteristics of the study site and the current agricultural water resource management have been described and analyzed. The study area is located in the western part of Romania. This region knows warm, dry summers and cold, wet winters. Because most of the crops have a growing period between April and September (including the dry summer months), irrigation is necessary (3000ha of the whole area is irrigated). In the last years often over-irrigation has taken place. Therefore it is necessary to change the current irrigation pattern. Also water sources are limited (only surface water is used for irrigation, because the groundwater is to brackish). So it is necessary to realize a sustainable water use with new irrigation patterns.

SPHY is used for the hydrological modeling, because it calculates actual evapotranspiration and soil moisture. The input is mostly global data. The data sets are chosen after an extensive data inventory and are assumed to be suitable for the research. With SPHY different model runs are executed.

The modeled results of several model runs are compared with measured values from the DACOM sensors. The absolute difference in water content of the root zone between measured and modeled values is smaller at a root depth of 400mm than at a root depth of 600mm. Though the absolute difference between measured and modeled data is still high, the distribution at probably non-irrigated locations is similar (R^2 values between 0.6 and 0.85, see Table 6-1: DACOM 1 and DACOM 5).

Within the second calibration step seepage has been added. By adding a seepage of 1.5mm/day the water content in the root zone nearly does not change and it is chosen not to use seepage in the following runs.

At the next calibration step different amounts of irrigation, based on the difference between potential and actual evapotranspiration (ET_{pot} resp. ET_{act}), have been simulated. The absolute difference in water content becomes smaller, but stagnates when the difference between ET_{pot} and ET_{act} becomes nearly zero. Also the R^2-values becomes smaller, so there is no linear relationship between measured and modeled values anymore. Reason for this could be, that in reality a different irrigation pattern is used.

For the last calibration step the static crop factors (one crop factor per land use for the whole year) have been changed into dynamic crop factors (different crop factors per growing stadium of the crops). This results in a higher water content during the begin of the growing season. Also the R^2 values become higher. So the distribution of the run with dynamic crop factors is more similar to the measured results. The results of this run are seen as the best possible, because due to global data the difference between measured and modeled values can never be zero. The measured values are sometimes even higher than the saturated water content in the model. Another reason for the much higher measured values could be too high measurements of the soil moisture sensors.

Table 6-1: R^2 of different runs

DACOM sensor	R^2 of runs with a root depth of 400mm			
	no irrigation static	irrigation*20 static	no irrigation dynamic	irrigation*20 dynamic
1	0.60	0.32	0.66	0.50
4	0.51	0.04	0.57	0.29
5	0.85	0.28	0.87	0.05
6	0.13	0.09	0.16	0.12
7	0.49	0.03	0.51	0.07
8	0.51	0.06	0.50	0.11
9	0.28	0.08	0.30	0.18
10	0.59	0.03	0.64	0.20

To answer the last sub question three scenarios are created:

- Fixed vs. scheduled irrigation
- Climate change
- Dry and wet seasons

Within the first scenario fixed irrigation is compared to scheduled irrigation. The scheduled irrigation results in a water content of the root zone around field capacity, which is higher than the water content reached with the fixed irrigation or irrigation based on the evapotranspiration deficit.

In the second and third scenario the effects of climate change (higher temperature, dry and wet seasons) are analyzed. Due to higher temperature the evapotranspiration rises and the water content decreases. Due to little rainfall in the dry season the water content decrease as well and in the wet season the water content rises. If no irrigation or fixed irrigation takes place, the influences of climate change on the water content are high. If scheduled irrigation is applied, there is nearly no difference in water content compared to the run without climate change. The scheduled irrigation pattern easily adapt to new situations by using more or less irrigation water. So there is no dry or wet damage, due to climate change or over irrigation, and the water is used on a sustainable way.

6.2 Discussion and Recommendations

Within this paragraph several points are discussed, and recommendations are given how this points can be improved in further research.

Global data

Within this research mainly global data is used. This could be one reason for the big differences with measured data. It is advised to execute the model runs again with local data, especially with a local and detailed soil map and with a map of the locations of the grown crops.

Irrigation pattern

When executing runs with different irrigation patterns, the absolute difference with measured data becomes smaller. But there is nearly no linear relationship between measured and modelled data, when irrigation is applied. Reason could be, that the irrigation pattern is different in reality. For a better calibration of the model, a model run should be executed with the irrigation pattern as used on the farm (same amounts of water and same days of irrigation).

Sensor data

Another reason for the big differences between measured and modelled data could be too high measurements of the DACOM-sensors. It is advised to control the reliability of the measurements and to rescale the results of the sensors if necessary.

Evapotranspiration deficit

At the model runs with irrigation (based on the evapotranspiration deficit) the water content in the root zone stagnates, because the difference between potential and actual evapotranspiration has become nearly zero. When the actual evapotranspiration reaches the same level as the potential evapotranspiration, it means that enough water is available to evaporate and transpire. But in this case the water content of the root zone stagnates at a level, which is similar to the wilting point. Normally more water should be in the root zone, otherwise the crop could not transpire for the whole 100% of the potential transpiration. It is advised to do further research on where the low water content in the root zone comes from.

Operational irrigation advice

The ultimate goal of the farmers in Romania is to have an online operational system that provides them with irrigation advice on a daily basis. After the model has been calibrated with local data, this will be the final step to be performed.

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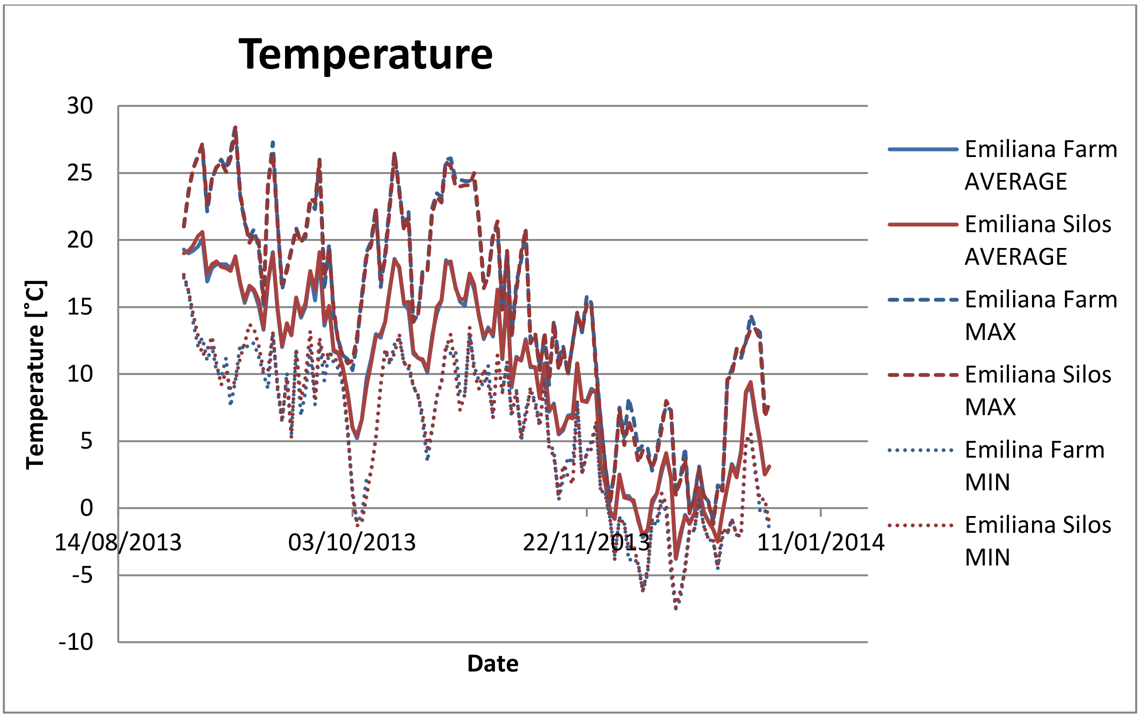
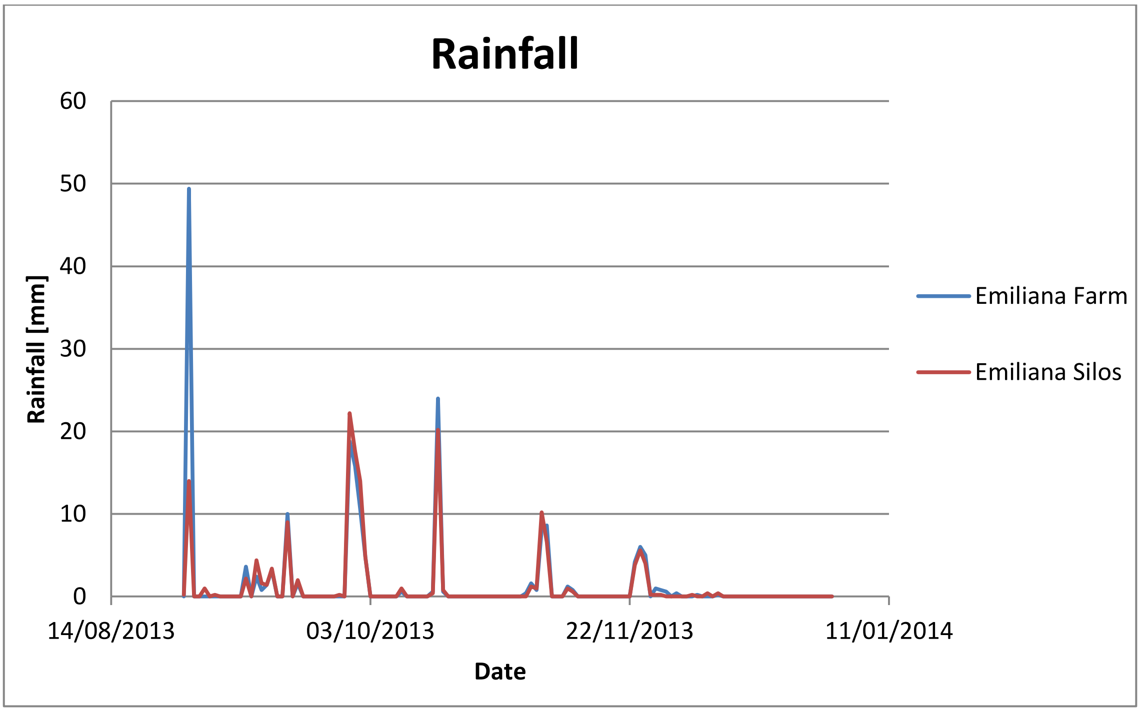
Appendix 1: Local data

1.1 DACOM Data

1.1.1 Difference between DACOM stations





1.1.2 DACOM climate data

Date	FARM EMILIANA				EMILIANA SILOS				AVERAGE			
	T Mean	T max	T min	Rain-fall	T Mean	T max	T min	Rain-fall	T Mean	T max	T min	Rain-fall
	˚C	˚C	˚C	mm	˚C	˚C	˚C	mm	˚C	˚C	˚C	mm
28/08/2013	19.3	21	17.2	0	19	21	17.4	0.2	19.15	21	17.3	0.1
29/08/2013	19	23.6	16.1	14	19.2	23.7	16.2	14	19.1	23.65	16.15	14
30/08/2013	19.2	25.3	13.9	0	19.6	25.3	14.5	0	19.4	25.3	14.2	0
31/08/2013	19.5	26.3	12.1	0	20.3	26.2	12.9	0	19.9	26.25	12.5	0
01/09/2013	20.1	26.9	12.7	0	20.6	27.2	11.4	1	20.35	27.05	12.05	0.5
02/09/2013	16.9	22.1	11	0	17.5	22.5	11.8	0	17.2	22.3	11.4	0
03/09/2013	17.9	24.5	12.1	0	18.2	24.6	12.8	0.2	18.05	24.55	12.45	0.1
04/09/2013	18.2	25.5	10.2	0	18.4	25.4	10.8	0	18.3	25.45	10.5	0
05/09/2013	18.2	26	9.8	0	18	25.8	9.2	0	18.1	25.9	9.5	0
06/09/2013	18.2	25.3	11.2	0	17.9	25.1	10.2	0	18.05	25.2	10.7	0
07/09/2013	17.9	26.6	7.6	0	17.7	26.1	8.9	0	17.8	26.35	8.25	0
08/09/2013	18.6	28.5	9.5	0	18.8	28.4	9.5	0	18.7	28.45	9.5	0
09/09/2013	16.7	23.3	12.2	3.6	16.8	23.5	11.2	2.2	16.75	23.4	11.7	2.9
10/09/2013	15.3	21.3	11.8	0	15.5	21.5	12.3	0	15.4	21.4	12.05	0
11/09/2013	16.4	20.2	12.3	2.4	16.6	19.8	13.7	4.4	16.5	20	13	3.4
12/09/2013	16.2	20.8	12.3	0.8	16.3	20.4	13.4	1.6	16.25	20.6	12.85	1.2
13/09/2013	15.1	19.4	11.3	1.4	15.5	19.9	12.1	1.4	15.3	19.65	11.7	1.4
14/09/2013	13.3	15.1	10	3.2	13.4	15.5	10.3	3.4	13.35	15.3	10.15	3.3
15/09/2013	16.8	24.1	8.9	0	17	24.2	10.2	0	16.9	24.15	9.55	0
16/09/2013	19.1	27.3	13.1	0	19	26.5	13.1	0	19.05	26.9	13.1	0
17/09/2013	14.7	21.3	8.8	10	14.9	21.2	9.1	9	14.8	21.25	8.95	9.5
18/09/2013	12	16.3	6.4	0	12.1	16.7	6.7	0	12.05	16.5	6.55	0
19/09/2013	13.7	17.9	10.1	1.6	13.8	17.7	9.7	2	13.75	17.8	9.9	1.8
20/09/2013	12.9	19.3	5.5	0	12.9	19.2	5.3	0	12.9	19.25	5.4	0
21/09/2013	15.7	20.9	11.8	0	15.7	20.8	11.9	0	15.7	20.85	11.85	0
22/09/2013	14.2	19.9	6.9	0	14.4	19.8	8.1	0	14.3	19.85	7.5	0
23/09/2013	15	20.2	8.7	0	15.3	20.5	9.8	0	15.15	20.35	9.25	0
24/09/2013	17.6	22.8	11.8	0	17.7	23.1	13.2	0	17.65	22.95	12.5	0
25/09/2013	15.5	22.3	7.7	0	16.3	22.8	8.2	0	15.9	22.55	7.95	0
26/09/2013	18.7	25.9	12.3	0	19.1	26	12.7	0	18.9	25.95	12.5	0
27/09/2013	13.6	16.3	9.5	0	13.9	17.2	10.9	0.2	13.75	16.75	10.2	0.1
28/09/2013	15	19.7	11.6	0	15.1	19.3	11.7	0	15.05	19.5	11.65	0
29/09/2013	11.7	14.4	10.9	18.8	11.8	14.9	11.1	22.2	11.75	14.65	11	20.5
30/09/2013	11.5	12.5	10.4	15.8	11.6	12.3	11	17.6	11.55	12.4	10.7	16.7
01/10/2013	10.4	11.4	9.1	10.6	10.5	11.4	9.4	14	10.45	11.4	9.25	12.3
02/10/2013	8.6	11.1	5.6	4.8	8.5	10.8	6	4.8	8.55	10.95	5.8	4.8
03/10/2013	6	10.3	1.3	0	6	11	1	0	6	10.65	1.15	0
04/10/2013	5.2	12.4	-1.1	0	5.4	12.8	-1.3	0	5.3	12.6	-1.2	0
05/10/2013	6.6	15.8	-0.5	0	6.6	15.5	-1.1	0	6.6	15.65	-0.8	0
06/10/2013	9.7	19.1	2.2	0	9.1	18.8	0.9	0	9.4	18.95	1.55	0
07/10/2013	11.1	19.9	2.6	0	10.8	19.6	2.8	0	10.95	19.75	2.7	0
08/10/2013	13	22.4	5.3	0	12.8	22.3	5.2	0	12.9	22.35	5.25	0
09/10/2013	12.7	16.5	9.2	0.6	13	17	9.1	1	12.85	16.75	9.15	0.8
10/10/2013	13.9	19	11.8	0	13.9	18.6	11.9	0	13.9	18.8	11.85	0
11/10/2013	16.4	23	10.7	0	16.4	22.6	11	0	16.4	22.8	10.85	0
12/10/2013	18.6	26.5	12.2	0	18.5	26.5	11.5	0	18.55	26.5	11.85	0
13/10/2013	17.9	23.8	12.6	0	18	23.6	13	0	17.95	23.7	12.8	0
14/10/2013	15.2	20.8	10.9	0	15.3	20.7	10.7	0	15.25	20.75	10.8	0
15/10/2013	14.8	22.1	10.4	0.6	15.4	21.7	10.9	0.4	15.1	21.9	10.65	0.5
16/10/2013	11.5	13.9	9.1	24	11.7	13.9	9.1	20.2	11.6	13.9	9.1	22.1
17/10/2013	11.2	14.5	8.3	0.6	11.2	14.5	8.4	0.8	11.2	14.5	8.35	0.7
18/10/2013	11	17.8	6.5	0	11.1	17.4	7	0	11.05	17.6	6.75	0
19/10/2013	10.1	17.8	3.5	0	10.3	17.7	4.5	0	10.2	17.75	4	0
20/10/2013	12.9	22.4	5.9	0	12.6	22	5.9	0	12.75	22.2	5.9	0
21/10/2013	14.5	23.5	8.3	0	15	23.2	8.3	0	14.75	23.35	8.3	0
22/10/2013	15.5	23.2	9.3	0	15.5	22.8	9.4	0	15.5	23	9.35	0
23/10/2013	18.5	26	12.2	0	18.3	25.8	11.9	0	18.4	25.9	12.05	0
24/10/2013	18.1	26.1	11.5	0	18.4	25.5	13	0	18.25	25.8	12.25	0

25/10/2013	16.5	24.5	11.7	0	16.4	24	10.1	0	16.45	24.25	10.9	0
26/10/2013	15.4	24.5	8.6	0	15.6	24	7.3	0	15.5	24.25	7.95	0
27/10/2013	15.1	24.4	8.6	0	15.6	24.1	8.5	0	15.35	24.25	8.55	0
28/10/2013	17.3	24.4	12.9	0	17.5	24.1	13.5	0	17.4	24.25	13.2	0
29/10/2013	16.3	24.5	10.6	0	16.7	25	10.1	0	16.5	24.75	10.35	0
30/10/2013	14.4	21.3	9.5	0	14.3	21.5	8.9	0	14.35	21.4	9.2	0
31/10/2013	12.6	16.9	9.1	0	12.8	16.4	10.4	0	12.7	16.65	9.75	0
01/11/2013	13.5	17.3	10.6	0	13.3	17.3	9.3	0	13.4	17.3	9.95	0
02/11/2013	12.8	20.5	6.7	0.4	13	20.3	6.8	0	12.9	20.4	6.75	0.2
03/11/2013	16.1	20.9	11.4	1.6	16.3	21.4	11.4	1.2	16.2	21.15	11.4	1.4
04/11/2013	11.1	14.6	8.7	0.8	11.2	14.8	8.6	1	11.15	14.7	8.65	0.9
05/11/2013	15.9	19.2	10.8	8.2	16	19.2	10.9	10.2	15.95	19.2	10.85	9.2
06/11/2013	9	12.9	6.8	8.6	9.2	12.7	7	6.6	9.1	12.8	6.9	7.6
07/11/2013	11.3	16.8	8.8	0	11.2	16.2	8.7	0	11.25	16.5	8.75	0
08/11/2013	11	18.5	5	0	11	19.1	5.3	0	11	18.8	5.15	0
09/11/2013	12.6	20.7	7.3	0	12.5	20.8	6.7	0	12.55	20.75	7	0
10/11/2013	10.5	12.5	8.7	1.2	10.6	12.3	9	1	10.55	12.4	8.85	1.1
11/11/2013	10.5	12.9	8	0.8	10.5	13	7.6	0.6	10.5	12.95	7.8	0.7
12/11/2013	8.2	10.4	6.2	0	8.2	10.3	6.1	0	8.2	10.35	6.15	0
13/11/2013	10.7	12.9	9.7	0	10.8	13.1	9.5	0	10.75	13	9.6	0
14/11/2013	7.2	9.2	4.8	0	7.3	9.6	4.5	0	7.25	9.4	4.65	0
15/11/2013	7.8	14	4.3	0	7.7	13.8	3.9	0	7.75	13.9	4.1	0
16/11/2013	5.5	11.2	0.6	0	5.6	10.3	0.9	0	5.55	10.75	0.75	0
17/11/2013	5.8	12.1	2.2	0	6	11.8	3.2	0	5.9	11.95	2.7	0
18/11/2013	6.9	9.9	3.8	0	6.8	10.1	2.4	0	6.85	10	3.1	0
19/11/2013	7	12.4	3.3	0	6.7	12.3	1.8	0	6.85	12.35	2.55	0
20/11/2013	10.8	14.5	7.9	0	10.8	14.6	7.9	0	10.8	14.55	7.9	0
21/11/2013	8	13.1	2.6	0	8	13.2	2.5	0	8	13.15	2.55	0
22/11/2013	8	15.8	4.2	0	7.9	15.2	4.1	0	7.95	15.5	4.15	0
23/11/2013	8.9	15.3	5	4.2	8.7	15.2	4.4	3.8	8.8	15.25	4.7	4
24/11/2013	8.7	10.7	6.3	6	8.7	10.1	6.5	5.6	8.7	10.4	6.4	5.8
25/11/2013	3.4	6.6	1.4	5	3.4	6.7	1.4	4	3.4	6.65	1.4	4.5
26/11/2013	1.9	3.1	1.1	0	1.8	3	1	0.2	1.85	3.05	1.05	0.1
27/11/2013	-0.2	0.5	-0.8	1	-0.3	0.4	-0.9	0.2	-0.25	0.45	-0.85	0.6
28/11/2013	-0.8	2.9	-3.5	0.8	-0.8	2.8	-3.8	0.2	-0.8	2.85	-3.65	0.5
29/11/2013	2.3	7.5	-0.7	0.6	2.5	7.4	-0.7	0	2.4	7.45	-0.7	0.3
30/11/2013	0.9	5.3	-1.1	0	0.8	4.7	-1.2	0	0.85	5	-1.15	0
01/12/2013	0.9	8.2	-3.9	0.4	0.7	6.5	-3	0	0.8	7.35	-3.45	0.2
02/12/2013	0.4	6.7	-3.7	0	0.6	5.4	-2.7	0	0.5	6.05	-3.2	0
03/12/2013	-0.8	4.3	-4.2	0	-1	3.4	-4.3	0	-0.9	3.85	-4.25	0
04/12/2013	-2.2	4.7	-6.2	0	-2	4.3	-6.2	0.2	-2.1	4.5	-6.2	0.1
05/12/2013	-1.7	4.5	-4.9	0.2	-1.6	3.9	-4.5	0	-1.65	4.2	-4.7	0.1
06/12/2013	0.3	2.8	-0.9	0	0.6	3	-0.9	0	0.45	2.9	-0.9	0
07/12/2013	1.1	4.3	-1.3	0	1.1	4	-0.8	0.4	1.1	4.15	-1.05	0.2
08/12/2013	2.7	6.5	0.6	0	3	5.9	1.1	0	2.85	6.2	0.85	0
09/12/2013	3.9	7.6	-0.3	0.2	4.1	8	0.3	0.4	4	7.8	0	0.3
10/12/2013	2.3	7.3	-4.9	0	2.2	7.3	-4	0	2.25	7.3	-4.45	0
11/12/2013	-3.8	1	-7.5	0	-3.7	1	-7.4	0	-3.75	1	-7.45	0
12/12/2013	-2.2	2.2	-6.8	0	-1.9	2	-6.2	0	-2.05	2.1	-6.5	0
13/12/2013	-0.5	4.5	-4.3	0	-0.6	3.7	-4.7	0	-0.55	4.1	-4.5	0
14/12/2013	-1.1	-0.3	-1.6	0	-1.2	-0.4	-1.6	0	-1.15	-0.35	-1.6	0
15/12/2013	-0.4	0.9	-1.7	0	-0.4	0.8	-1.6	0	-0.4	0.85	-1.65	0
16/12/2013	1.5	3.1	0.7	0	1.5	3	0.7	0	1.5	3.05	0.7	0
17/12/2013	-0.2	0.9	-1.3	0	-0.3	1	-1.3	0	-0.25	0.95	-1.3	0
18/12/2013	-1	0.5	-2.3	0	-1	0.4	-2.3	0	-1	0.45	-2.3	0
19/12/2013	-1.6	-1	-2.5	0	-1.6	-1.2	-2.4	0	-1.6	-1.1	-2.45	0
20/12/2013	-2.5	1.7	-4.5	0	-2.5	1.5	-4.4	0	-2.5	1.6	-4.45	0
21/12/2013	-0.3	1.5	-2.2	0	-0.3	1.3	-1.5	0	-0.3	1.4	-1.85	0
22/12/2013	1.6	9.5	-1.9	0	1.6	9.6	-1.9	0	1.6	9.55	-1.9	0
23/12/2013	3.3	10.4	-0.8	0	3.2	9.9	-0.8	0	3.25	10.15	-0.8	0
24/12/2013	2.6	11.7	-2	0	2.3	11.9	-2	0	2.45	11.8	-2	0
25/12/2013	4.3	11.2	-1.9	0	4.1	11.5	-2.1	0	4.2	11.35	-2	0
26/12/2013	8.6	12.4	5	0	8.7	12.4	5	0	8.65	12.4	5	0
27/12/2013	9.1	14.4	5.3	0	9.4	13.4	5.6	0	9.25	13.9	5.45	0

28/12/2013	6.9	13.5	3.1	0	7.2	13.4	2.7	0	7.05	13.45	2.9	0
29/12/2013	4.9	13.1	-0.2	0	5.1	12.6	0.6	0	5	12.85	0.2	0
30/12/2013	2.5	7.3	-0.1	0	2.5	6.8	0.7	0	2.5	7.05	0.3	0
31/12/2013	3.1	8	-1.5	0	3.1	7.8	-1.1	0	3.1	7.9	-1.3	0

Appendix 2: Global data

2.1 Overview global datasets

Name/organization	Website	Data type	Resolution	Coordinate system	Year	Remarks
Soil						
Harmonized World Soil Database	http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/	Grid	30 arcsec (~1kmx1km)	WGS_1984	2012	World scale → not very detailed, but more detailed than other global sets.
Digital Soil Map of the world / FAO, Unesco	http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116	Polygon	-	-	2003	World scale → not detailed enough. Missing coordinate system
ISRIC	www.isric.org	Polygon	-	WGS_1984	2005	For whole East-Europe → not detailed enough compared to HWSD
Joint research centre	http://eusoils.jrc.ec.europa.eu/	-	-	-	-	GIS-data could not be found, only pdf's.
Climate						
CRU	http://www.cru.uea.ac.uk/cru/data/hrg/	-	-	-	-	No datasets for 2013
GSOD	http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html	-	-	-	-	The right data set could not be found.
Weather underground	http://wunderground.com	Time series	Day values	-	2013	Nearest weather station: Szeged (Hungary). Only point measurements of one station, no radar data.
DEM						
SRTM	http://www2.jpl.nasa.gov/srtm/	-	90m	-	-	Right dataset could not be found.
Aster gedem	http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.html	-	30m	-	-	Right dataset could not be found.
EEA	http://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-original-data	Grid	~30x30m	ETRS89	2013?	Differs from indications of topographic base map (ESRI)
Land cover						
EEA	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2	Grid	~100x100m	ETRS89	-	No irrigation areas
Global irrigated Area map	http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm	Grid	5 arc minutes	WGS_1984	2013	Very rough. 51,83% of areas equipped for irrigation are actually irrigated. Total size of this areas are much less than 4000 ha.
Global land cover facility	http://www.landcover.org/index.shtml	Grid	~1x1km	WGS_1984	1981-1994	Very rough. Data not up to date.

2.2 Climate data

2.2.1 Changed Climate Data - Weather underground

Date	Temperature High [˚C]	Temperature Average [˚C]	Temperature Low [˚C]	Precipitation [mm]
1/1/2013	-1	-3	-5	0.00
1/2/2013	-1	-3	-5	0.00
1/3/2013	8	0	-5	0.00
1/4/2013	10	6	3	0.00
1/5/2013	15	5	0	1.50
1/6/2013	3	0	-3	0.00
1/7/2013	2	-1	-7	1.50
1/8/2013	0	-5	-8	1.00
1/9/2013	-2	-4	-5	0.00
1/10/2013	1	0	-2	1.00
1/11/2013	11	1	-3	1.50
1/12/2013	3	-3	-7	0.00
1/13/2013	2	-1	-3	0.00
1/14/2013	9	2	0	1.50
1/15/2013	8	5	2	3.00
1/16/2013	10	4	3	5.10
1/17/2013	5	3	2	1.50
1/18/2013	2	0	0	8.90
1/19/2013	-1	-3	-4	0.00
1/20/2013	7	2	-2	2.00
1/21/2013	19	9	7	0.00
1/22/2013	4	2	-2	0.50
1/23/2013	3	1	-2	0.00
1/24/2013	5	1	-2	0.00
1/25/2013	0	-1	-3	0.00
1/26/2013	8	-2	-4	0.00
1/27/2013	3	-1	-2	0.00
1/28/2013	2	0	-2	0.00
1/29/2013	11	1	-2	0.00
1/30/2013	7	6	5	3.60
1/31/2013	17	7	2	2.00
2/1/2013	12	6	1	0.00
2/2/2013	16	6	4	9.90
2/3/2013	4	1	-2	4.60
2/4/2013	10	0	-3	0.50
2/5/2013	13	3	-1	0.00
2/6/2013	11	4	1	0.50
2/7/2013	12	2	-1	0.50
2/8/2013	5	2	-1	0.00
2/9/2013	9	-1	-4	0.50
2/10/2013	9	-1	-3	2.00
2/11/2013	7	-3	-7	1.50
2/12/2013	4	2	-3	0.50
2/13/2013	9	5	1	1.50
2/14/2013	14	4	2	4.60
2/15/2013	7	4	3	0.00
2/16/2013	4	3	1	0.00
2/17/2013	3	1	-1	0.00
2/18/2013	3	1	-2	0.00
2/19/2013	8	1	-3	0.00
2/20/2013	8	3	-1	0.50
2/21/2013	3	0	-2	0.00
2/22/2013	2	0	-1	6.10
2/23/2013	8	4	0	3.00
2/24/2013	8	6	5	4.60
2/25/2013	13	10	5	5.10
2/26/2013	17	7	6	4.10
2/27/2013	15	5	4	4.60

2/28/2013	7	4	-1	0.50
3/1/2013	7	2	-2	0.00
3/2/2013	10	3	-3	0.00
3/3/2013	11	2	-4	0.00
3/4/2013	10	2	-3	0.00
3/5/2013	13	3	-3	0.00
3/6/2013	17	8	2	0.00
3/7/2013	11	9	7	0.00
3/8/2013	21	13	7	0.00
3/9/2013	19	13	9	2.50
3/10/2013	15	11	8	8.40
3/11/2013	13	8	5	0.00
3/12/2013	18	8	2	2.00
3/13/2013	17	7	5	2.00
3/14/2013	8	4	-2	12.40
3/15/2013	-1	-3	-4	0.00
3/16/2013	4	-2	-7	5.60
3/17/2013	3	-2	-8	0.00
3/18/2013	5	2	-2	0.50
3/19/2013	13	7	2	5.10
3/20/2013	17	8	2	0.00
3/21/2013	10	6	2	20.30
3/22/2013	7	2	-2	4.60
3/23/2013	6	1	-3	0.00
3/24/2013	0	-2	-6	0.00
3/25/2013	0	-2	-3	0.00
3/26/2013	2	0	-2	0.00
3/27/2013	10	1	-1	10.90
3/28/2013	5	-2	-8	3.00
3/29/2013	8	3	-3	5.60
3/30/2013	19	9	4	16.00
3/31/2013	17	9	3	4.10
4/1/2013	11	4	0	0.00
4/2/2013	15	5	1	18.50
4/3/2013	8	6	3	1.00
4/4/2013	7	5	2	0.00
4/5/2013	7	5	3	7.40
4/6/2013	17	7	3	0.50
4/7/2013	10	6	1	0.00
4/8/2013	14	6	1	0.00
4/9/2013	14	8	4	1.00
4/10/2013	20	10	5	1.00
4/11/2013	19	11	5	0.00
4/12/2013	21	13	7	1.00
4/13/2013	21	13	7	0.50
4/14/2013	20	12	6	0.00
4/15/2013	18	11	5	0.00
4/16/2013	21	12	6	0.00
4/17/2013	24	14	8	0.00
4/18/2013	25	15	9	0.00
4/19/2013	24	15	9	0.00
4/20/2013	26	16	10	0.00
4/21/2013	25	17	11	0.00
4/22/2013	25	17	11	0.00
4/23/2013	25	17	11	0.00
4/24/2013	27	17	11	0.00
4/25/2013	29	19	13	0.00
4/26/2013	30	20	14	0.00
4/27/2013	30	21	15	0.00
4/28/2013	28	20	14	0.00
4/29/2013	31	21	15	0.00
4/30/2013	33	23	17	0.00
5/1/2013	33	24	18	0.00
5/2/2013	33	23	17	0.00

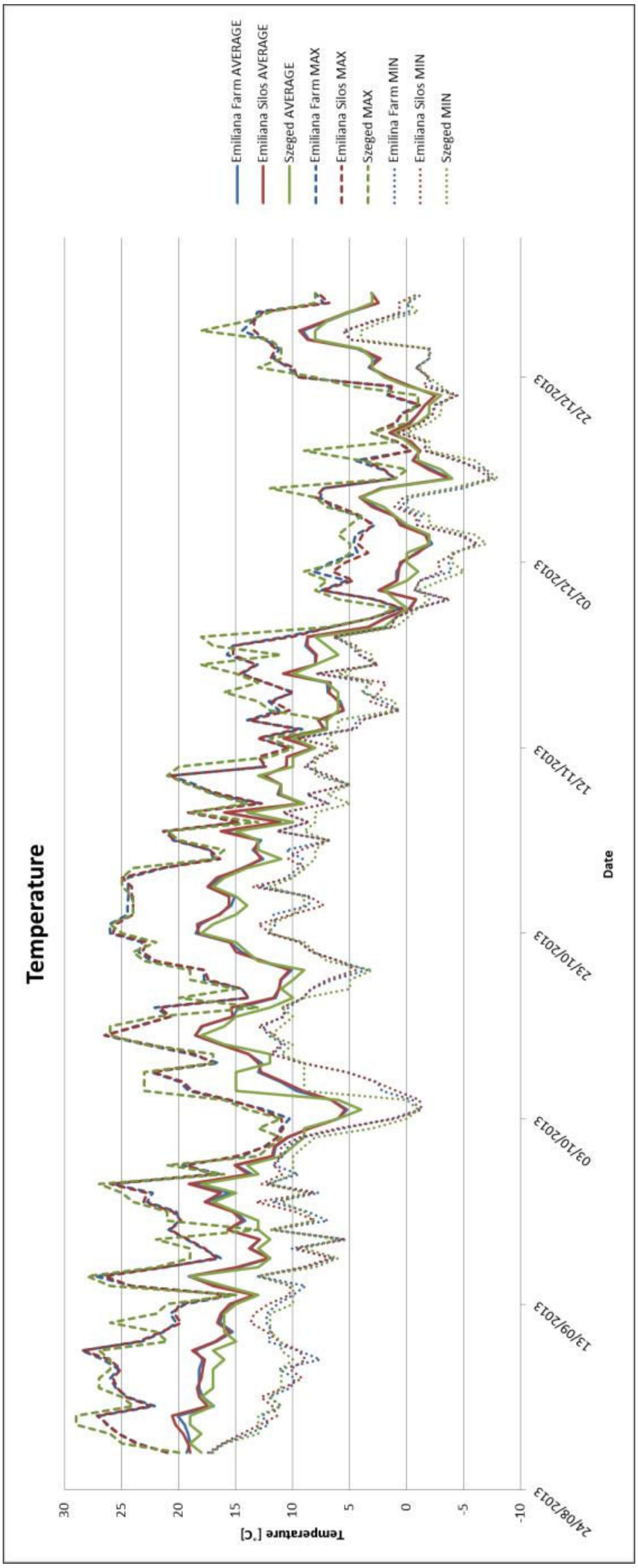
5/3/2013	30	22	16	0.00
5/4/2013	28	20	14	0.00
5/5/2013	27	20	14	0.00
5/6/2013	28	20	15	16.50
5/7/2013	24	18	15	9.40
5/8/2013	29	19	15	0.50
5/9/2013	25	19	14	0.00
5/10/2013	28	20	14	0.00
5/11/2013	29	20	14	1.50
5/12/2013	19	16	13	0.00
5/13/2013	13	12	10	1.50
5/14/2013	20	13	7	0.00
5/15/2013	23	16	10	0.00
5/16/2013	28	19	13	0.00
5/17/2013	25	18	14	18.50
5/18/2013	25	18	12	0.50
5/19/2013	30	21	15	2.00
5/20/2013	26	19	13	0.00
5/21/2013	24	18	12	1.00
5/22/2013	19	14	11	13.00
5/23/2013	18	14	11	0.00
5/24/2013	20	15	10	0.00
5/25/2013	20	15	11	0.00
5/26/2013	14	11	8	4.60
5/27/2013	16	11	7	12.40
5/28/2013	20	15	10	0.50
5/29/2013	26	19	13	0.50
5/30/2013	21	16	10	8.90
5/31/2013	22	14	8	0.50
6/1/2013	19	13	9	0.50
6/2/2013	21	15	12	0.00
6/3/2013	19	14	11	0.00
6/4/2013	16	13	11	0.00
6/5/2013	22	16	12	2.00
6/6/2013	24	17	11	0.00
6/7/2013	25	19	13	8.40
6/8/2013	28	21	15	0.00
6/9/2013	31	23	17	0.00
6/10/2013	30	20	15	2.50
6/11/2013	27	19	13	0.50
6/12/2013	27	20	14	0.00
6/13/2013	28	24	18	0.00
6/14/2013	33	23	17	0.00
6/15/2013	34	24	18	0.00
6/16/2013	34	25	19	0.00
6/17/2013	37	27	21	0.00
6/18/2013	35	25	19	0.00
6/19/2013	37	29	23	0.00
6/20/2013	37	29	23	0.00
6/21/2013	38	28	22	0.00
6/22/2013	38	29	23	5.60
6/23/2013	31	25	20	0.50
6/24/2013	29	23	17	25.90
6/25/2013	18	16	13	1.00
6/26/2013	21	15	10	0.00
6/27/2013	23	16	10	0.00
6/28/2013	25	17	11	0.00
6/29/2013	26	17	11	0.00
6/30/2013	27	18	12	10.40
7/1/2013	26	19	13	0.00
7/2/2013	29	20	14	0.00
7/3/2013	30	22	16	0.00
7/4/2013	32	23	17	0.00
7/5/2013	32	24	18	0.00

7/6/2013	33	25	19	0.50
7/7/2013	32	25	19	0.50
7/8/2013	32	25	19	1.00
7/9/2013	31	23	18	0.00
7/10/2013	33	24	18	0.00
7/11/2013	31	21	16	18.00
7/12/2013	27	20	14	0.00
7/13/2013	29	20	14	0.00
7/14/2013	29	21	15	0.00
7/15/2013	30	21	15	0.00
7/16/2013	27	20	14	0.00
7/17/2013	31	22	16	0.00
7/18/2013	33	23	17	0.00
7/19/2013	33	24	18	0.00
7/20/2013	31	26	21	0.00
7/21/2013	28	22	16	0.00
7/22/2013	31	22	16	0.00
7/23/2013	34	24	18	0.00
7/24/2013	35	25	19	0.00
7/25/2013	33	24	18	0.00
7/26/2013	34	25	19	0.00
7/27/2013	36	26	20	0.00
7/28/2013	37	28	22	0.00
7/29/2013	39	29	23	0.00
7/30/2013	29	24	19	3.60
7/31/2013	32	23	17	0.00
8/1/2013	34	25	19	0.00
8/2/2013	35	26	20	0.00
8/3/2013	37	27	21	0.00
8/4/2013	36	28	22	0.00
8/5/2013	36	27	21	0.00
8/6/2013	38	28	22	0.00
8/7/2013	38	28	22	0.00
8/8/2013	39	29	23	0.00
8/9/2013	39	29	23	0.00
8/10/2013	31	25	19	0.00
8/11/2013	30	23	17	0.00
8/12/2013	34	24	18	0.00
8/13/2013	35	25	19	0.00
8/14/2013	29	22	18	0.00
8/15/2013	30	21	15	0.00
8/16/2013	30	22	16	0.00
8/17/2013	32	22	16	0.00
8/18/2013	34	24	18	0.00
8/19/2013	36	26	20	0.00
8/20/2013	33	24	18	0.00
8/21/2013	25	21	18	0.00
8/22/2013	29	21	15	0.00
8/23/2013	30	23	17	0.00
8/24/2013	30	22	17	0.00
8/25/2013	30	22	16	2.00
8/26/2013	29	19	16	4.10
8/27/2013	28	20	15	0.00
8/28/2013	20	18	17	19.60
8/29/2013	25	19	16	11.40
8/30/2013	26	18	13	0.50
8/31/2013	29	19	13	0.00
9/1/2013	29	19	13	0.00
9/2/2013	24	17	11	0.00
9/3/2013	25	18	12	0.00
9/4/2013	27	17	11	0.00
9/5/2013	27	17	11	0.00
9/6/2013	26	17	11	0.00
9/7/2013	26	16	10	0.00

9/8/2013	27	17	11	0.00
9/9/2013	21	15	11	2.00
9/10/2013	22	16	12	0.00
9/11/2013	26	16	12	5.60
9/12/2013	22	16	12	1.00
9/13/2013	21	15	10	4.60
9/14/2013	15	13	10	2.50
9/15/2013	26	16	10	0.00
9/16/2013	28	19	13	2.00
9/17/2013	22	13	8	7.40
9/18/2013	19	12	6	0.00
9/19/2013	19	13	9	1.50
9/20/2013	22	12	6	0.00
9/21/2013	13	13	12	0.00
9/22/2013	21	13	8	0.00
9/23/2013	21	15	9	0.00
9/24/2013	24	17	11	0.00
9/25/2013	25	15	9	0.00
9/26/2013	27	18	12	0.00
9/27/2013	16	13	10	0.00
9/28/2013	21	14	10	0.00
9/29/2013	13	11	10	10.40
9/30/2013	12	10	9	12.40
10/1/2013	11	9	8	10.40
10/2/2013	13	9	3	2.00
10/3/2013	11	6	0	0.00
10/4/2013	14	4	-1	0.00
10/5/2013	16	6	0	0.00
10/6/2013	23	15	9	0.00
10/7/2013	23	15	9	0.00
10/8/2013	23	15	9	0.00
10/9/2013	17	12	9	2.00
10/10/2013	17	12	11	1.50
10/11/2013	23	16	10	0.50
10/12/2013	26	18	12	0.00
10/13/2013	26	16	11	0.00
10/14/2013	22	15	10	0.00
10/15/2013	13	12	11	0.00
10/16/2013	20	10	9	21.80
10/17/2013	15	11	5	2.50
10/18/2013	19	10	5	0.50
10/19/2013	19	9	3	0.00
10/20/2013	23	13	7	0.00
10/21/2013	24	14	8	0.00
10/22/2013	22	15	9	0.00
10/23/2013	25	18	12	0.00
10/24/2013	26	17	12	0.00
10/25/2013	24	15	10	0.00
10/26/2013	24	14	9	0.00
10/27/2013	24	15	9	0.00
10/28/2013	25	17	12	0.00
10/29/2013	25	16	10	0.00
10/30/2013	24	14	9	0.00
10/31/2013	17	11	8	0.00
11/1/2013	16	13	8	0.00
11/2/2013	20	13	7	2.00
11/3/2013	21	15	9	2.50
11/4/2013	13	10	8	0.50
11/5/2013	19	14	8	11.90
11/6/2013	14	9	5	2.00
11/7/2013	17	11	7	0.00
11/8/2013	19	11	5	0.00
11/9/2013	21	13	8	0.00
11/10/2013	20	10	8	1.50

11/11/2013	12	10	8	3.00
11/12/2013	10	8	6	0.00
11/13/2013	12	10	7	0.00
11/14/2013	7	7	6	0.00
11/15/2013	7	7	6	0.00
11/16/2013	12	6	1	0.00
11/17/2013	13	6	1	0.00
11/18/2013	16	6	4	0.00
11/19/2013	13	7	3	0.00
11/20/2013	15	10	6	0.00
11/21/2013	18	8	3	0.50
11/22/2013	11	6	3	0.00
11/23/2013	17	7	5	7.40
11/24/2013	18	8	6	3.00
11/25/2013	7	2	1	6.10
11/26/2013	3	1	0	0.00
11/27/2013	1	0	-1	0.00
11/28/2013	6	1	-2	0.00
11/29/2013	8	2	-1	0.00
11/30/2013	7	0	-3	0.00
12/1/2013	9	-1	-5	0.00
12/2/2013	6	0	-4	0.00
12/3/2013	5	0	-4	0.00
12/4/2013	5	-2	-7	0.00
12/5/2013	6	-2	-6	0.00
12/6/2013	5	0	-2	0.00
12/7/2013	4	1	-2	0.00
12/8/2013	7	2	0	0.00
12/9/2013	8	4	0	0.00
12/10/2013	12	2	-4	0.00
12/11/2013	1	-4	-8	0.00
12/12/2013	0	-3	-7	0.00
12/13/2013	4	-1	-6	0.00
12/14/2013	9	-1	-2	0.00
12/15/2013	1	0	-2	0.00
12/16/2013	3	1	0	0.00
12/17/2013	0	-1	-2	0.00
12/18/2013	0	-2	-3	0.00
12/19/2013	-1	-2	-3	0.00
12/20/2013	-1	-3	-4	0.00
12/21/2013	5	0	-3	0.00
12/22/2013	8	2	-2	0.00
12/23/2013	13	3	-1	0.00
12/24/2013	11	3	-2	0.00
12/25/2013	11	4	-2	0.00
12/26/2013	12	8	4	0.00
12/27/2013	18	8	4	0.00
12/28/2013	14	7	2	0.00
12/29/2013	12	5	-1	0.00
12/30/2013	8	3	0	0.00
12/31/2013	8	3	-1	0.00

2.2.2 Difference DACOM and weather underground



2.2.3 Combined data set weather underground and DACOM weather stations

Date	Temperature High [˚C]	Temperature Average [˚C]	Temperature Low [˚C]	Precipitation [mm]
01/01/2013	-1	-3	-5	0
02/01/2013	-1	-3	-5	0
03/01/2013	8	0	-5	0
04/01/2013	10	6	3	0
05/01/2013	15	5	0	1.5
06/01/2013	3	0	-3	0
07/01/2013	2	-1	-7	1.5
08/01/2013	0	-5	-8	1
09/01/2013	-2	-4	-5	0
10/01/2013	1	0	-2	1
11/01/2013	11	1	-3	1.5
12/01/2013	3	-3	-7	0
13/01/2013	2	-1	-3	0
14/01/2013	9	2	0	1.5
15/01/2013	8	5	2	3
16/01/2013	10	4	3	5.1
17/01/2013	5	3	2	1.5
18/01/2013	2	0	0	8.9
19/01/2013	-1	-3	-4	0
20/01/2013	7	2	-2	2
21/01/2013	19	9	7	0
22/01/2013	4	2	-2	0.5
23/01/2013	3	1	-2	0
24/01/2013	5	1	-2	0
25/01/2013	0	-1	-3	0
26/01/2013	8	-2	-4	0
27/01/2013	3	-1	-2	0
28/01/2013	2	0	-2	0
29/01/2013	11	1	-2	0
30/01/2013	7	6	5	3.6
31/01/2013	17	7	2	2
01/02/2013	12	6	1	0
02/02/2013	16	6	4	9.9
03/02/2013	4	1	-2	4.6
04/02/2013	10	0	-3	0.5
05/02/2013	13	3	-1	0
06/02/2013	11	4	1	0.5
07/02/2013	12	2	-1	0.5
08/02/2013	5	2	-1	0
09/02/2013	9	-1	-4	0.5
10/02/2013	9	-1	-3	2
11/02/2013	7	-3	-7	1.5
12/02/2013	4	2	-3	0.5
13/02/2013	9	5	1	1.5
14/02/2013	14	4	2	4.6
15/02/2013	7	4	3	0
16/02/2013	4	3	1	0
17/02/2013	3	1	-1	0
18/02/2013	3	1	-2	0
19/02/2013	8	1	-3	0
20/02/2013	8	3	-1	0.5
21/02/2013	3	0	-2	0
22/02/2013	2	0	-1	6.1
23/02/2013	8	4	0	3
24/02/2013	8	6	5	4.6
25/02/2013	13	10	5	5.1
26/02/2013	17	7	6	4.1
27/02/2013	15	5	4	4.6
28/02/2013	7	4	-1	0.5
01/03/2013	7	2	-2	0
02/03/2013	10	3	-3	0

03/03/2013	11	2	-4	0
04/03/2013	10	2	-3	0
05/03/2013	13	3	-3	0
06/03/2013	17	8	2	0
07/03/2013	11	9	7	0
08/03/2013	21	13	7	0
09/03/2013	19	13	9	2.5
10/03/2013	15	11	8	8.4
11/03/2013	13	8	5	0
12/03/2013	18	8	2	2
13/03/2013	17	7	5	2
14/03/2013	8	4	-2	12.4
15/03/2013	-1	-3	-4	0
16/03/2013	4	-2	-7	5.6
17/03/2013	3	-2	-8	0
18/03/2013	5	2	-2	0.5
19/03/2013	13	7	2	5.1
20/03/2013	17	8	2	0
21/03/2013	10	6	2	20.3
22/03/2013	7	2	-2	4.6
23/03/2013	6	1	-3	0
24/03/2013	0	-2	-6	0
25/03/2013	0	-2	-3	0
26/03/2013	2	0	-2	0
27/03/2013	10	1	-1	10.9
28/03/2013	5	-2	-8	3
29/03/2013	8	3	-3	5.6
30/03/2013	19	9	4	16
31/03/2013	17	9	3	4.1
01/04/2013	11	4	0	0
02/04/2013	15	5	1	18.5
03/04/2013	8	6	3	1
04/04/2013	7	5	2	0
05/04/2013	7	5	3	7.4
06/04/2013	17	7	3	0.5
07/04/2013	10	6	1	0
08/04/2013	14	6	1	0
09/04/2013	14	8	4	1
10/04/2013	20	10	5	1
11/04/2013	19	11	5	0
12/04/2013	21	13	7	1
13/04/2013	21	13	7	0.5
14/04/2013	20	12	6	0
15/04/2013	18	11	5	0
16/04/2013	21	12	6	0
17/04/2013	24	14	8	0
18/04/2013	25	15	9	0
19/04/2013	24	15	9	0
20/04/2013	26	16	10	0
21/04/2013	25	17	11	0
22/04/2013	25	17	11	0
23/04/2013	25	17	11	0
24/04/2013	27	17	11	0
25/04/2013	29	19	13	0
26/04/2013	30	20	14	0
27/04/2013	30	21	15	0
28/04/2013	28	20	14	0
29/04/2013	31	21	15	0
30/04/2013	33	23	17	0
01/05/2013	33	24	18	0
02/05/2013	33	23	17	0
03/05/2013	30	22	16	0
04/05/2013	28	20	14	0
05/05/2013	27	20	14	0

06/05/2013	28	20	15	16.5
07/05/2013	24	18	15	9.4
08/05/2013	29	19	15	0.5
09/05/2013	25	19	14	0
10/05/2013	28	20	14	0
11/05/2013	29	20	14	1.5
12/05/2013	19	16	13	0
13/05/2013	13	12	10	1.5
14/05/2013	20	13	7	0
15/05/2013	23	16	10	0
16/05/2013	28	19	13	0
17/05/2013	25	18	14	18.5
18/05/2013	25	18	12	0.5
19/05/2013	30	21	15	2
20/05/2013	26	19	13	0
21/05/2013	24	18	12	1
22/05/2013	19	14	11	13
23/05/2013	18	14	11	0
24/05/2013	20	15	10	0
25/05/2013	20	15	11	0
26/05/2013	14	11	8	4.6
27/05/2013	16	11	7	12.4
28/05/2013	20	15	10	0.5
29/05/2013	26	19	13	0.5
30/05/2013	21	16	10	8.9
31/05/2013	22	14	8	0.5
01/06/2013	19	13	9	0.5
02/06/2013	21	15	12	0
03/06/2013	19	14	11	0
04/06/2013	16	13	11	0
05/06/2013	22	16	12	2
06/06/2013	24	17	11	0
07/06/2013	25	19	13	8.4
08/06/2013	28	21	15	0
09/06/2013	31	23	17	0
10/06/2013	30	20	15	2.5
11/06/2013	27	19	13	0.5
12/06/2013	27	20	14	0
13/06/2013	28	24	18	0
14/06/2013	33	23	17	0
15/06/2013	34	24	18	0
16/06/2013	34	25	19	0
17/06/2013	37	27	21	0
18/06/2013	35	25	19	0
19/06/2013	37	29	23	0
20/06/2013	37	29	23	0
21/06/2013	38	28	22	0
22/06/2013	38	29	23	5.6
23/06/2013	31	25	20	0.5
24/06/2013	29	23	17	25.9
25/06/2013	18	16	13	1
26/06/2013	21	15	10	0
27/06/2013	23	16	10	0
28/06/2013	25	17	11	0
29/06/2013	26	17	11	0
30/06/2013	27	18	12	10.4
01/07/2013	26	19	13	0
02/07/2013	29	20	14	0
03/07/2013	30	22	16	0
04/07/2013	32	23	17	0
05/07/2013	32	24	18	0
06/07/2013	33	25	19	0.5
07/07/2013	32	25	19	0.5
08/07/2013	32	25	19	1

09/07/2013	31	23	18	0
10/07/2013	33	24	18	0
11/07/2013	31	21	16	18
12/07/2013	27	20	14	0
13/07/2013	29	20	14	0
14/07/2013	29	21	15	0
15/07/2013	30	21	15	0
16/07/2013	27	20	14	0
17/07/2013	31	22	16	0
18/07/2013	33	23	17	0
19/07/2013	33	24	18	0
20/07/2013	31	26	21	0
21/07/2013	28	22	16	0
22/07/2013	31	22	16	0
23/07/2013	34	24	18	0
24/07/2013	35	25	19	0
25/07/2013	33	24	18	0
26/07/2013	34	25	19	0
27/07/2013	36	26	20	0
28/07/2013	37	28	22	0
29/07/2013	39	29	23	0
30/07/2013	29	24	19	3.6
31/07/2013	32	23	17	0
01/08/2013	34	25	19	0
02/08/2013	35	26	20	0
03/08/2013	37	27	21	0
04/08/2013	36	28	22	0
05/08/2013	36	27	21	0
06/08/2013	38	28	22	0
07/08/2013	38	28	22	0
08/08/2013	39	29	23	0
09/08/2013	39	29	23	0
10/08/2013	31	25	19	0
11/08/2013	30	23	17	0
12/08/2013	34	24	18	0
13/08/2013	35	25	19	0
14/08/2013	29	22	18	0
15/08/2013	30	21	15	0
16/08/2013	30	22	16	0
17/08/2013	32	22	16	0
18/08/2013	34	24	18	0
19/08/2013	36	26	20	0
20/08/2013	33	24	18	0
21/08/2013	25	21	18	0
22/08/2013	29	21	15	0
23/08/2013	30	23	17	0
24/08/2013	30	22	17	0
25/08/2013	30	22	16	2
26/08/2013	29	19	16	4.1
27/08/2013	28	20	15	0
28/08/2013	21	19.15	17.3	0.1
29/08/2013	23.65	19.1	16.15	14
30/08/2013	25.3	19.4	14.2	0
31/08/2013	26.25	19.9	12.5	0
01/09/2013	27.05	20.35	12.05	0.5
02/09/2013	22.3	17.2	11.4	0
03/09/2013	24.55	18.05	12.45	0.1
04/09/2013	25.45	18.3	10.5	0
05/09/2013	25.9	18.1	9.5	0
06/09/2013	25.2	18.05	10.7	0
07/09/2013	26.35	17.8	8.25	0
08/09/2013	28.45	18.7	9.5	0
09/09/2013	23.4	16.75	11.7	2.9
10/09/2013	21.4	15.4	12.05	0

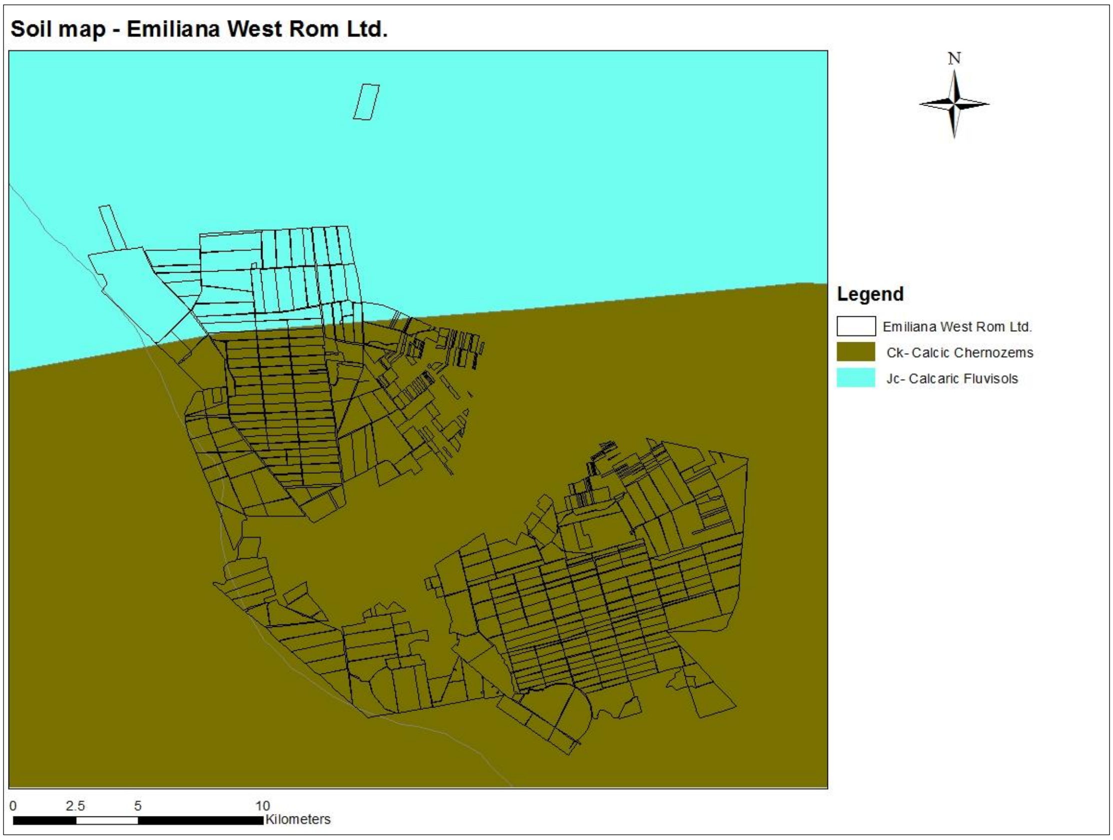
11/09/2013	20	16.5	13	3.4
12/09/2013	20.6	16.25	12.85	1.2
13/09/2013	19.65	15.3	11.7	1.4
14/09/2013	15.3	13.35	10.15	3.3
15/09/2013	24.15	16.9	9.55	0
16/09/2013	26.9	19.05	13.1	0
17/09/2013	21.25	14.8	8.95	9.5
18/09/2013	16.5	12.05	6.55	0
19/09/2013	17.8	13.75	9.9	1.8
20/09/2013	19.25	12.9	5.4	0
21/09/2013	20.85	15.7	11.85	0
22/09/2013	19.85	14.3	7.5	0
23/09/2013	20.35	15.15	9.25	0
24/09/2013	22.95	17.65	12.5	0
25/09/2013	22.55	15.9	7.95	0
26/09/2013	25.95	18.9	12.5	0
27/09/2013	16.75	13.75	10.2	0.1
28/09/2013	19.5	15.05	11.65	0
29/09/2013	14.65	11.75	11	20.5
30/09/2013	12.4	11.55	10.7	16.7
01/10/2013	11.4	10.45	9.25	12.3
02/10/2013	10.95	8.55	5.8	4.8
03/10/2013	10.65	6	1.15	0
04/10/2013	12.6	5.3	-1.2	0
05/10/2013	15.65	6.6	-0.8	0
06/10/2013	18.95	9.4	1.55	0
07/10/2013	19.75	10.95	2.7	0
08/10/2013	22.35	12.9	5.25	0
09/10/2013	16.75	12.85	9.15	0.8
10/10/2013	18.8	13.9	11.85	0
11/10/2013	22.8	16.4	10.85	0
12/10/2013	26.5	18.55	11.85	0
13/10/2013	23.7	17.95	12.8	0
14/10/2013	20.75	15.25	10.8	0
15/10/2013	21.9	15.1	10.65	0.5
16/10/2013	13.9	11.6	9.1	22.1
17/10/2013	14.5	11.2	8.35	0.7
18/10/2013	17.6	11.05	6.75	0
19/10/2013	17.75	10.2	4	0
20/10/2013	22.2	12.75	5.9	0
21/10/2013	23.35	14.75	8.3	0
22/10/2013	23	15.5	9.35	0
23/10/2013	25.9	18.4	12.05	0
24/10/2013	25.8	18.25	12.25	0
25/10/2013	24.25	16.45	10.9	0
26/10/2013	24.25	15.5	7.95	0
27/10/2013	24.25	15.35	8.55	0
28/10/2013	24.25	17.4	13.2	0
29/10/2013	24.75	16.5	10.35	0
30/10/2013	21.4	14.35	9.2	0
31/10/2013	16.65	12.7	9.75	0
01/11/2013	17.3	13.4	9.95	0
02/11/2013	20.4	12.9	6.75	0.2
03/11/2013	21.15	16.2	11.4	1.4
04/11/2013	14.7	11.15	8.65	0.9
05/11/2013	19.2	15.95	10.85	9.2
06/11/2013	12.8	9.1	6.9	7.6
07/11/2013	16.5	11.25	8.75	0
08/11/2013	18.8	11	5.15	0
09/11/2013	20.75	12.55	7	0
10/11/2013	12.4	10.55	8.85	1.1
11/11/2013	12.95	10.5	7.8	0.7
12/11/2013	10.35	8.2	6.15	0
13/11/2013	13	10.75	9.6	0

14/11/2013	9.4	7.25	4.65	0
15/11/2013	13.9	7.75	4.1	0
16/11/2013	10.75	5.55	0.75	0
17/11/2013	11.95	5.9	2.7	0
18/11/2013	10	6.85	3.1	0
19/11/2013	12.35	6.85	2.55	0
20/11/2013	14.55	10.8	7.9	0
21/11/2013	13.15	8	2.55	0
22/11/2013	15.5	7.95	4.15	0
23/11/2013	15.25	8.8	4.7	4
24/11/2013	10.4	8.7	6.4	5.8
25/11/2013	6.65	3.4	1.4	4.5
26/11/2013	3.05	1.85	1.05	0.1
27/11/2013	0.45	-0.25	-0.85	0.6
28/11/2013	2.85	-0.8	-3.65	0.5
29/11/2013	7.45	2.4	-0.7	0.3
30/11/2013	5	0.85	-1.15	0
01/12/2013	7.35	0.8	-3.45	0.2
02/12/2013	6.05	0.5	-3.2	0
03/12/2013	3.85	-0.9	-4.25	0
04/12/2013	4.5	-2.1	-6.2	0.1
05/12/2013	4.2	-1.65	-4.7	0.1
06/12/2013	2.9	0.45	-0.9	0
07/12/2013	4.15	1.1	-1.05	0.2
08/12/2013	6.2	2.85	0.85	0
09/12/2013	7.8	4	0	0.3
10/12/2013	7.3	2.25	-4.45	0
11/12/2013	1	-3.75	-7.45	0
12/12/2013	2.1	-2.05	-6.5	0
13/12/2013	4.1	-0.55	-4.5	0
14/12/2013	-0.35	-1.15	-1.6	0
15/12/2013	0.85	-0.4	-1.65	0
16/12/2013	3.05	1.5	0.7	0
17/12/2013	0.95	-0.25	-1.3	0
18/12/2013	0.45	-1	-2.3	0
19/12/2013	-1.1	-1.6	-2.45	0
20/12/2013	1.6	-2.5	-4.45	0
21/12/2013	1.4	-0.3	-1.85	0
22/12/2013	9.55	1.6	-1.9	0
23/12/2013	10.15	3.25	-0.8	0
24/12/2013	11.8	2.45	-2	0
25/12/2013	11.35	4.2	-2	0
26/12/2013	12.4	8.65	5	0
27/12/2013	13.9	9.25	5.45	0
28/12/2013	13.45	7.05	2.9	0
29/12/2013	12.85	5	0.2	0
30/12/2013	7.05	2.5	0.3	0
31/12/2013	7.9	3.1	-1.3	0

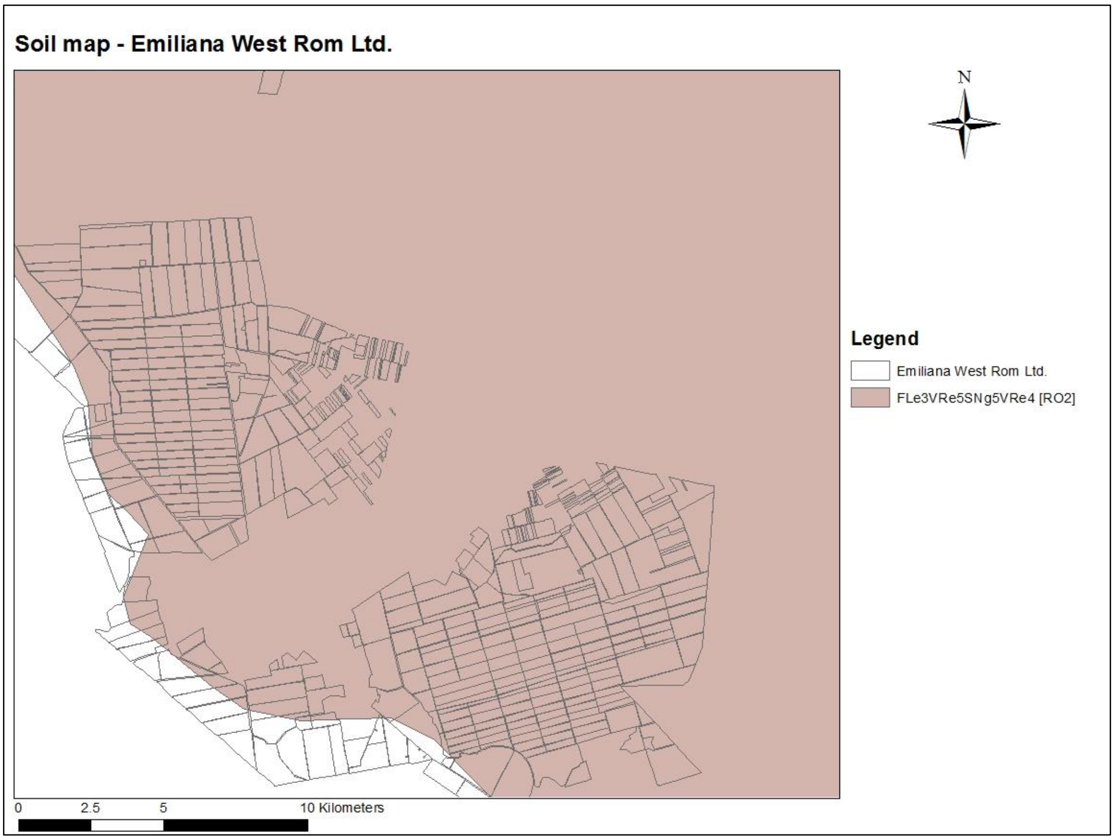
2.3 Soil

Below different soil maps can be found.

2.3.1 Digital Soil Map of the World



2.3.2 *ISRIC*

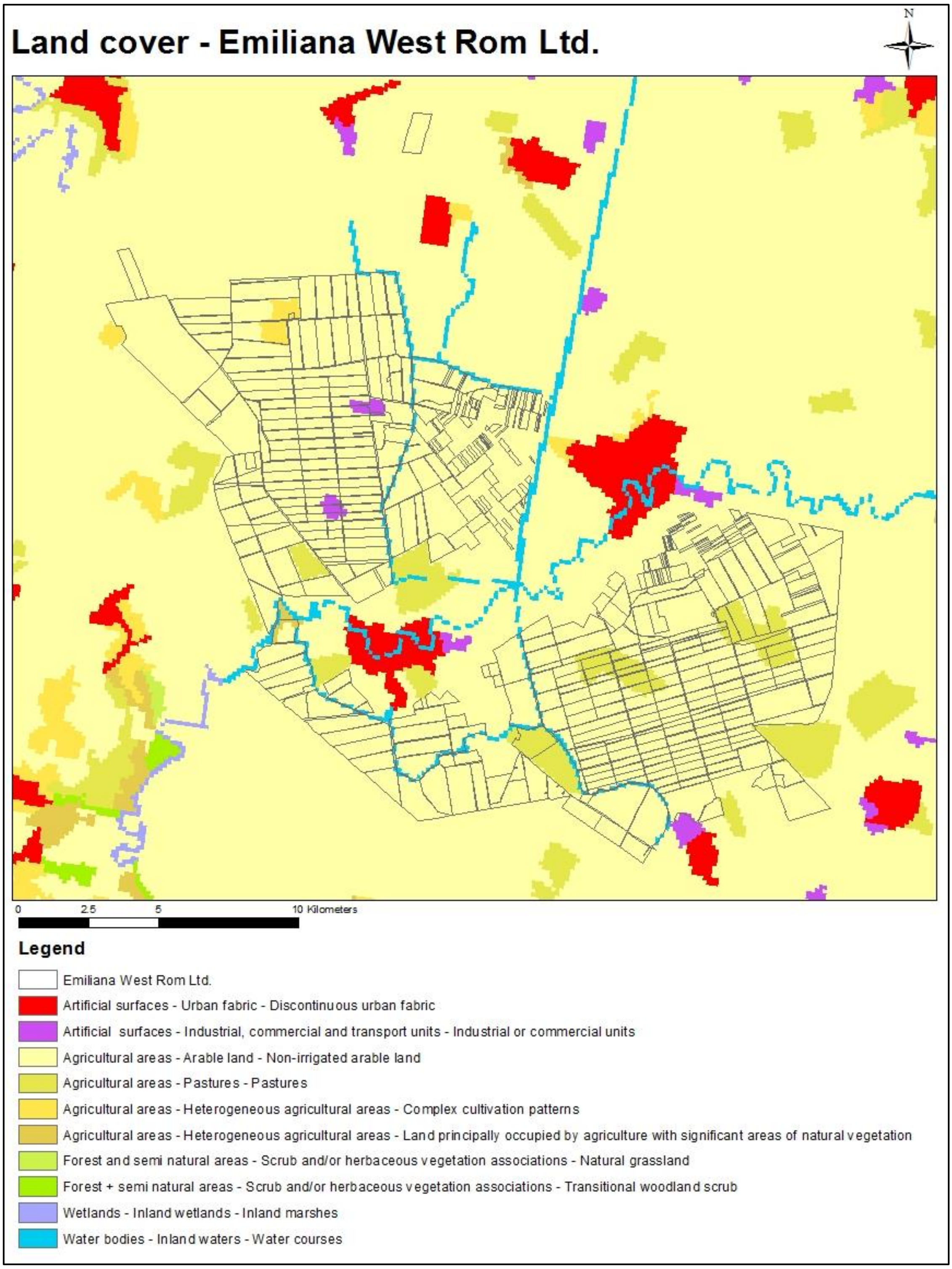


2.4 Land cover

Below different land cover maps can be found. The land cover map in chapter three is based on the last two maps.

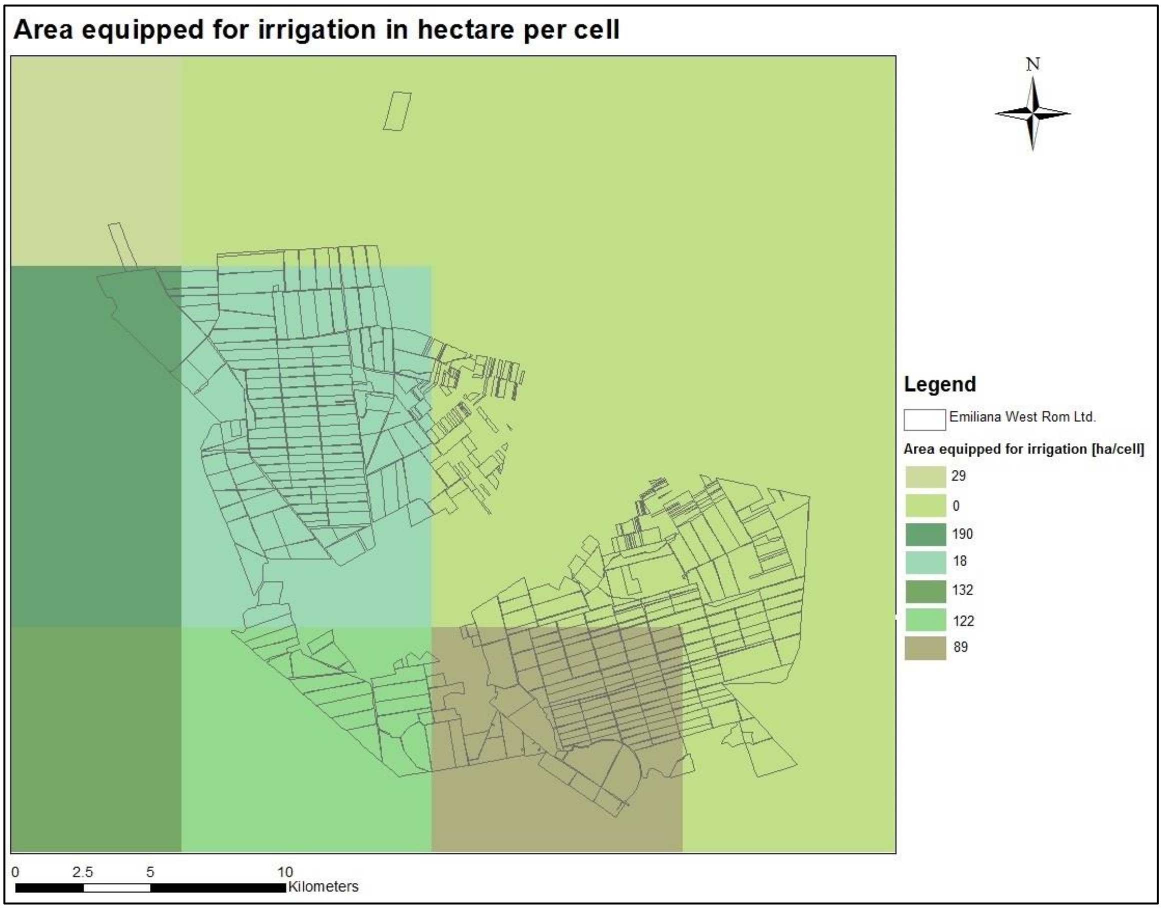
2.4.1 Global Land cover Facility

2.4.2 EEA



Land cover - Emiliana West Rom Ltd.
N
0
2.5
5
10 Kilometers
Legend
Emiliana West Rom Ltd.
Artificial surfaces - Urban fabric - Discontinuous urban fabric
Artificial surfaces - Industrial, commercial and transport units - Industrial or commercial units
Agricultural areas - Arable land - Non-irrigated arable land
Agricultural areas - Pastures - Pastures
Agricultural areas - Heterogeneous agricultural areas - Complex cultivation patterns
Agricultural areas - Heterogeneous agricultural areas - Land principally occupied by agriculture with significant areas of natural vegetation
Forest and semi natural areas - Scrub and/or herbaceous vegetation associations - Natural grassland
Forest + semi natural areas - Scrub and/or herbaceous vegetation associations - Transitional woodland scrub
Wetlands - Inland wetlands - Inland marshes
Water bodies - Inland waters - Water courses

2.4.3 Global Irrigated Area Map



2.5 Crop factors

	Crop characteristic	*Initial*	*Crop Development*	*Mid-season*	*Late*	*Total*	*Plant date*
Maize/ corn	Stage length, days	30	40	50	30	150	April
	Root Depth	0.3	>>	>>	1	-	
	Crop coefficient, Kc	0.3	>>	1.2	0.5	-	
Sun-flower	Stage length, days	25	35	45	25	130	April/May
	Root Depth	0.3	>>	>>	1.3	-	
	Crop coefficient, Kc	0.35	>>	1.0 (n.i.)-1.15 (irr.)	0.35	-	
Sugar-beet	Stage length, days	30	45	90	15	180	March
	Root Depth	0.3	>>	>>	1	-	
	Crop coefficient, Kc	0.35	>>	1.2	0.7	-	
Soy-bean	Stage length, days	20	30/35	60	25	140	May
	Root Depth	0.3	>>	>>	1	-	
	Crop coefficient, Kc	0.5	>>	1.5	0.5	-	
Raps	Stage length, days						
	Root Depth				1.0-1.5		
	Crop coefficient, Kc		1.0 (n.i.)-1.15 (irr.)	0.35			
Wheat	Stage length, days	30	140	40	30	240	November
	Root Depth	0.3	>>	>>	1.4	-	
	Crop coefficient, Kc	0.4	>>	1.15	0.25-0.4	-	
Average	Stage length, days	27	55	57	25	164	April
	Root depth	0.3	>>	>>	1.1	-	
	Kc	0.37	>>	1.1	0.48	-	