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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes

IRMA

WP5

Irrigation management tools

Action 5.5 Pilot operation and evaluation of the irrigation information and recommendation systems

Deliverable 5.5.1. Case studies for the system in Greece

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IRMA info

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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes (IRMA)

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Decentralised Administration of Epirus–Western Macedonia

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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes (IRMA)

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Deliverable 5.5.1.: Case studies for the system in Greece

Involved partners: TEIEP (LP)

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Place and time: Arta, 2015

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Contents

Tables

Figures

Equations

Introduction

The IRMA project concept states that with the given infrastructure, irrigation systems efficiency in both farm and irrigation scheme level could almost immediately increase if more reasonable water management was applied. In this framework the development of tools for real time data based cultivations water needs estimation and automatic generation of recommendations for improved irrigation schedules is of great importance.

Static or web based practical software has already been developed in order to assist agro-meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies. Good examples are CropWat (FAO) and CIMIS. Also irrigation companies have introduced evapotranspiration (ET) controllers for use in agricultural and landscape systems. In Greece relevant attempts have until now produced mainly static software. Evaluation of these tools showed impressive results as it is reported reduction on water consumption for irrigation at levels of 20% (olives at the island of Crete) and of 45% (landscape irrigation at California USA). In every case these tools should be adjusted for local conditions and this presupposes the knowledge of the special characteristics of the cultivations for each region and of the local irrigation practice. Operating examples of "real time" meteorological data, web based irrigation scheduling systems in the IRMA project area are ProBioSis (Greece) and Agrometeopuglia (Italy). More analytical information for relevant tools is provided in IRMA Deliverable 5.3.1. (Plan of IRMA_sys).

According to the latest USA Farm and Ranch Irrigation Survey (NASS, 2014): “in 2013, there were 229,237 farms with 55.3 million irrigated acres in the United States. From the variety of available data it is very interesting to analyse the responses regarding what method farmers use in deciding when to irrigate. All farms responded in this question and of them, the condition of the crop was the method used in 179,490 farms, followed by the feel of the soil (90,361), personal calendar scheduling (49,048), scheduled by water delivery organization (37,301), soil moisture sensing device (22,656 – 9.88%), commercial or government scheduling service (17,982 – 7.84%), reports on daily crop water evaporation, ET (17,815 – 7.81%). Interesting enough is that more than 13,000 farms responded that they start irrigating when their neighbor begins. Plant moisture sensing devices are used in 3,669 farms. The least used are the computer simulation models (1,915 farms – 0.84%).”. This fact is impressive and provides a sense of how much work has to be done in this sector.

The use of sensors for irrigation management in Greece and South Italy is very limited. Simple empirical settings using fixed scheduling during the whole irrigation period is the most common practice. In this framework we think that the existence of solid results regarding the expected benefits of using more efficiently irrigation controllers would be of great interest.

The IRMA_sys web service for irrigation information and recommendations (http://arta.irrigation-management.eu/) was developed for IRMA project. In the framework of the present evaluation, the service is tested for the case of turfgrass during the summer-fall period of 2015. The evaluation fields where at the Kostakii Campus of the Technological Education Institute of Epirus. The reference treatment was an irrigation system equipped with a controller that used water budget periods.

Also two other case studies are presented, one of which regards a kiwi-fruits orchard while the other a tangerine orchard. Both fields where located at the plain of Arta. For these cases the applied water during the summer-fall period of 2015 is compared to that proposed by IRMA_sys.

IRMA_sys in a glance

The Region of Epirus is located at the North-West part of Greece, it has a total area of 9.203km^2 and a population of 353.820 p. Agricultural land corresponds to the 14% of its total area. The plain of Arta (45.329 ha, the biggest of the region, Fig. 1), is located at the south of Epirus, it is part of the racthos and Louros hydrological basins (GR14 and GR46 according to WFD, 2013) and borders with Amvrakikos Wetlands National Park. The general water management plan for the Region of Epirus (EU Water Framework Directive (WFD) 2000/60/EC (EU, 2000)) was published in 2013 (WFD, 2013).

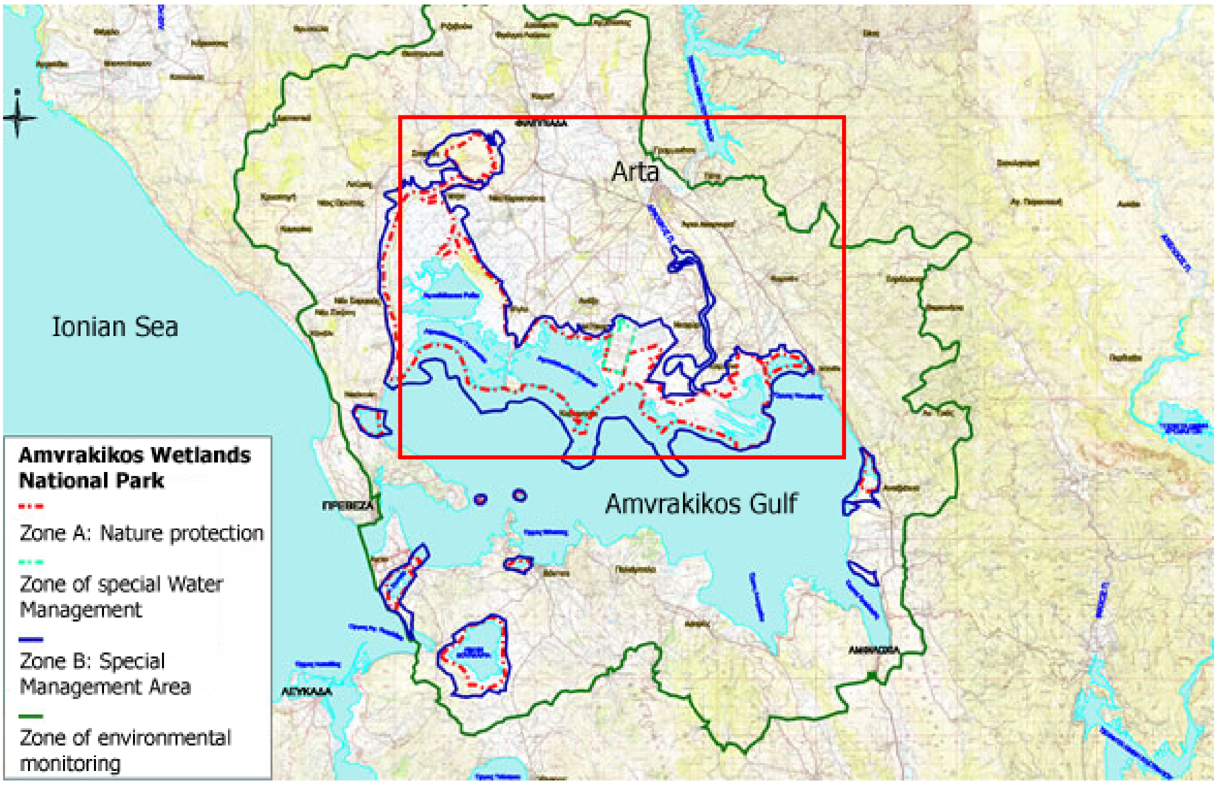


Fig. 1 The plain of Arta (red rectangle), the IRMA_SYS Arta area (base map: AWMD, 2014)

The climate of Arta's plain is of Mediterranean type, with hot summers and rainy moderate winters (Gouvas and Sakellariou, 2011). According to Tselepidakis and Theoharatos (1989), all of Western Greece is categorized in the meso-Mediterranean climate with a lower mean yearly number of dry days. Data from the local state meteorological station (HNMS, 2014; Longitude 21^{o}0'0" / Latitude 39^{o}10'0" / Alt 10.5m; recording period: 1976-1997) have been used to develop an ombrothermic diagram (Gaussen (1952), Fig. 2).

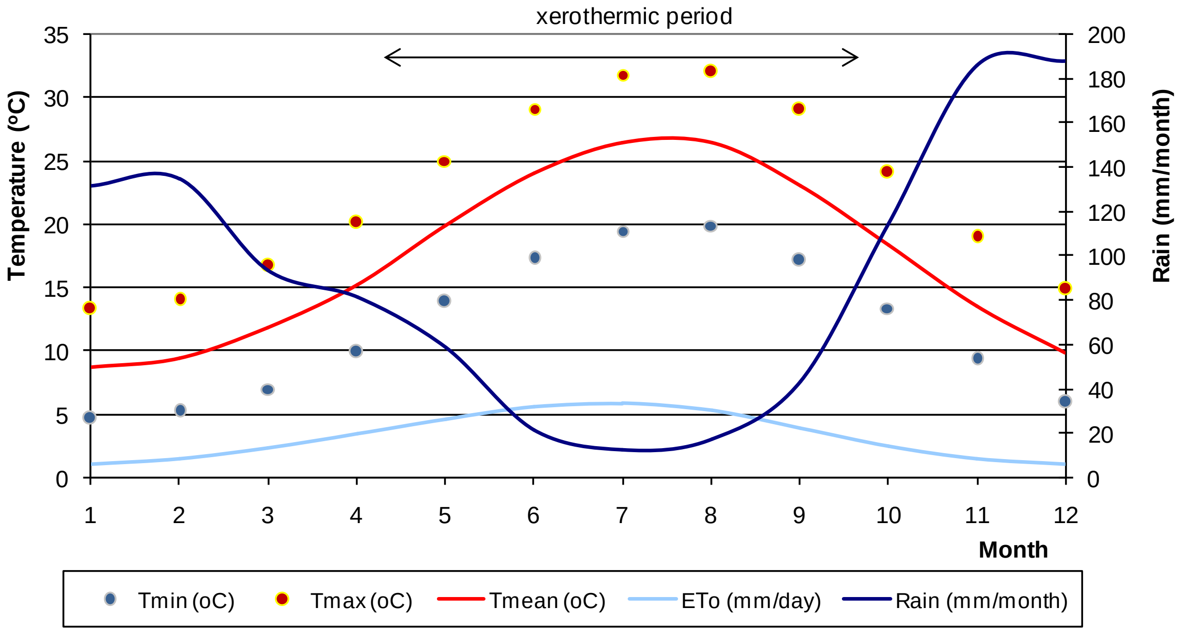


Fig. 2 Gaussen's ombrothermic diagram (T in °C, R in mm month^{-1} / xerothermic period, data from HNMS Arta MS)

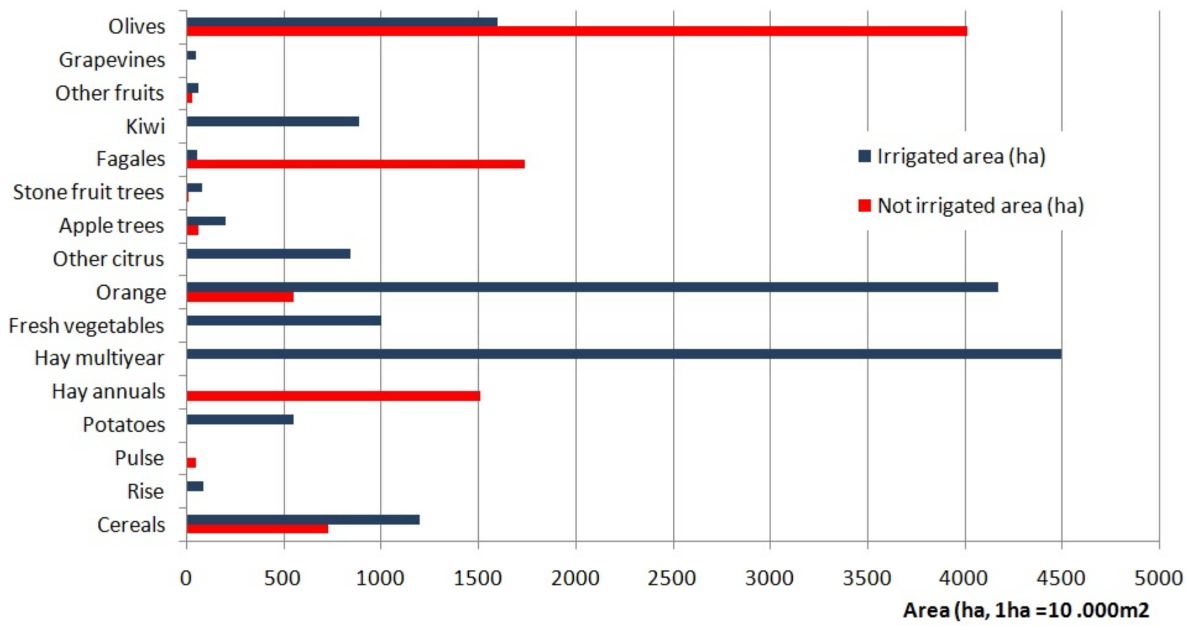


Fig. 3 Cultivations of the plain of Arta (Directorate of Agriculture of the Regional Sector of Arta, 2012)

Both Ministries that involved in irrigation water management (Environment Energy & Climate Change and Agricultural Development and Foods, operate relevant offices in Epirus, with branches at the Regional Sector of Arta. The plain of Arta is included in the area of responsibility of the Decentralised

Administration of Epirus and West Macedonia and of the Directorate of Agricultural Economy and Veterinary of Arta which is a branch of the Region of Epirus.

In the plain of Arta, a participatory irrigation project (Arta), which is still under construction, operates for more than 40 years at the west part of the plain, while at the east part (Peta-Kompoti) the works are at initial stage (Fig. 4). The authorities responsible for water management of this public irrigation project is the General Organization of Land Reclamation (GOLR) of Arta which collaborates with a number of Local Organizations of Land Reclamation (LOLR). These operate the Arta scheme, while the Peta - Kompoti scheme does not operates.

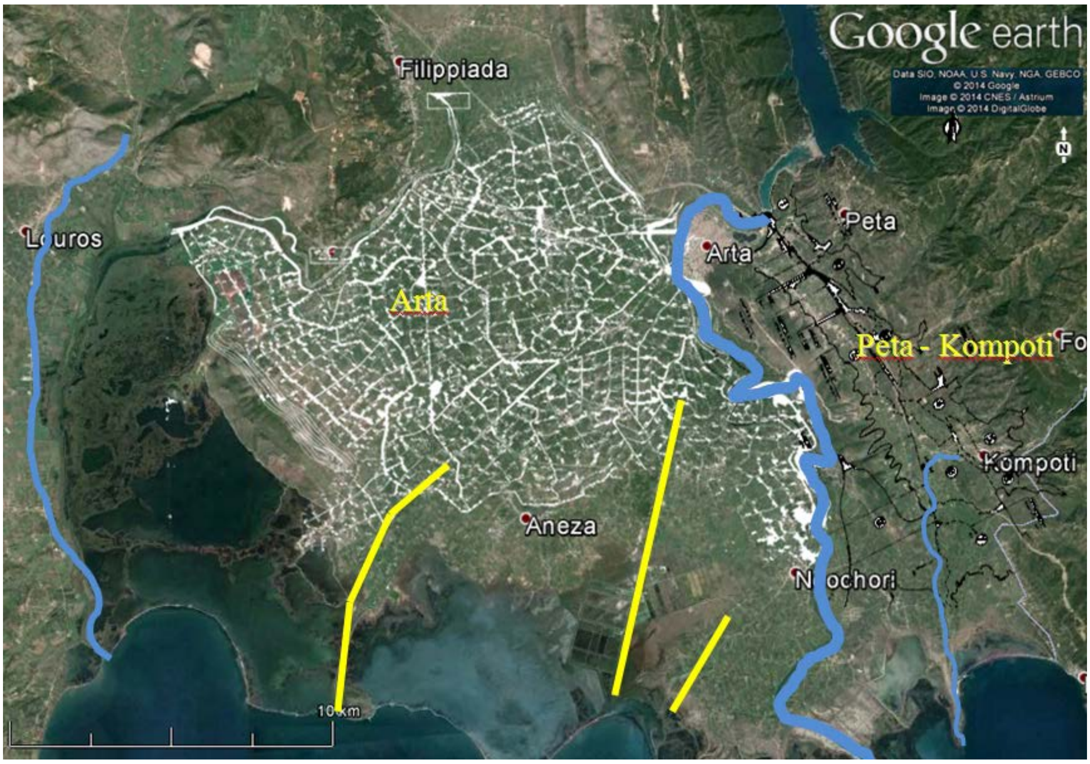


Fig. 4 The irrigation scheme of the plain of Arta (white lines; Arta (west part); black lines; Peta-Kompoti (east part)), the 3 rivers (blue lines; from left to right: Louros, Aracthos and Vovos and the 3 main drainage canals of the plain (yellow lines; from left to right: Salaoras (DC1), Fidocastrou (DC2) and Neochoriou (DC3))

No electronic registration of both descriptive and spatial data exists and the management is done manually based on the experience of the personnel.

Irrigation in the area is performed by means of surface irrigation, sprinkler irrigation and drip systems in proportions of about 40%, 40% and 20% respectively (Tsirogiannis and Triantos, 2009), with a continuous diminution of surface irrigation. The vast majority of farmers irrigate based on experience and inherited practical advices. As water is plentiful and cheap, most farmers over irrigate using water by the old open canal scheme that covers part of the plain and from numerous drillings most of which are illegal. Except of deep percolation, the main pathways of agricultural run-off and drainage are three rivers (Louros, Aracthos and Vovos) and three main draining canals (Salaoras, Fidokastrou and Neochoriou).

The groups of farmers that apply integrated management provide special information regarding cultivation techniques (including irrigation) for the cultivation they are specialized to. For the plain of Arta, even it includes citrus, kiwi-trees and olive trees in its integrated management system, provides an irrigation advices sheet only for the last one ASAF (2012a). During application of the integrated management system, each farmer should register -among others- all the irrigation events and relevant information using the provided by ASAF template (Fig. 5).

ΑΡΔΕΥΣΗ

Κωδικοί Αγροτεμαχίων	Τρόπος ποτίσματος	Προέλευση νερού	Ποσότητα νερού	Συχνότητα ποτίσματος

ΕΞΑΙΡΕΤΙΚΑ ΚΑΙΡΙΚΑ ΦΑΙΝΟΜΕΝΑ

Αγροτεμάχια	Ημερομηνία	Παγετός Ένταση ζημίας	Χαλάζι Ένταση ζημίας	Ανεμοθύελλα Ένταση ζημίας	Καύσωνας Ένταση ζημίας
	__/__/__				
	__/__/__				

Fig. 5 Extract from the farmers field diary (page 3 of 4; ASAF, 2012b)

According to Tsirogiannis et al. (2012), for the main irrigated cultivations (which represent only the 51% of the total irrigated agricultural land) of the plain of Arta, a total of about 50 Mm^3 of water is expected to be used per year for irrigation using the current managerial practices. Thus, the potential for savings is very high.

Environmental issues

Agricultural activity at the river basins of Louros and Aracthos is the major threat for the ecosystem of the park (WFD, 2014). Pollutants (fertilizers, pesticides etc.) find their way to Amvrakikos, while over-irrigation is causing salinisation of the water table (which is very shallow), but the problem is still not significant (Karras et al., 2006; Karras et al., 2007). During the last decade, the market problems regarding the orange cultivations, results limited interest for harvesting the fruits which are left to fall on the soil and decay. The relevant effluents are a new threat for both ground and underground water. Floods, which are common in the area, are also responsible for the transportation of fertilizers and other contaminants to the sea.

Fig. 6 Typical aspects of crop production effects on landscape in the area

The general concept of IRMA_sys

The Technological Educational Institute of Epirus (partner LP-TEIEP of IRMA project) developed from scratch a new web based irrigation advice system. The system was be a product of cooperation between experts in the fields of meteorological data acquisition, agricultural cultivation and landscapes water needs, irrigation management, irrigation controllers manufacturing and software developers.

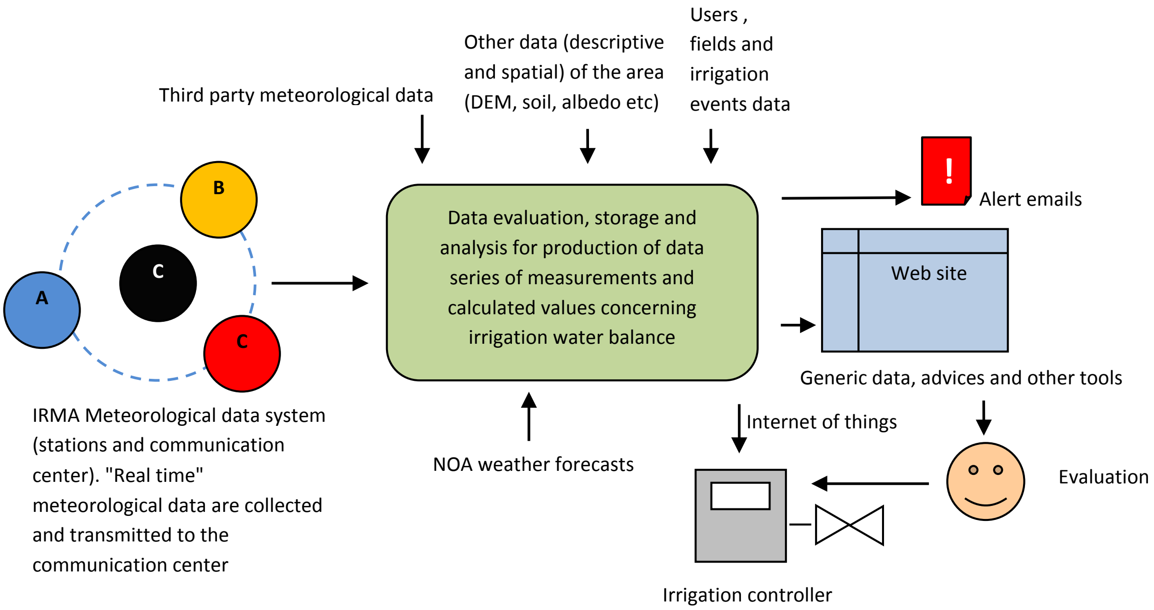


Fig. 7 IRMA system schematics

The system uses data from a dense network of agrometeorological stations that Decentralised Administration of Epirus and Western Macedonia (partner P6-ROEDM of IRMA project) has installed at the plain of Arta. The system outputs are already available through a relevant website. Agriculturalists, green infrastructure managers, farmers and gardeners are able to use the system for setting up irrigation schedules, plan and record irrigation events as well as self-training regarding irrigation management.

The system is available at http://arta.irrigation-management.eu/. It has to be kept well in mind that the philosophy of the service is to provide local agronomists with information and assistance regarding irrigation management. The service cannot substitute experts.

The basic concept of IRMA_sys is:

- Model the areas (abstraction and simplification procedure) characteristics that are involved in the irrigation water balance.
- Provide base information (proposals for soil, system, crops and irrigation management)
- Use actual meteorological and soil moisture data to continuously update the calculation of irrigation water balance parameters

- Offer information and assistance to the agronomist (irrigation manager / consultant) to guide by their turn, farmers and anyone interested, how to manage irrigation more efficiently.

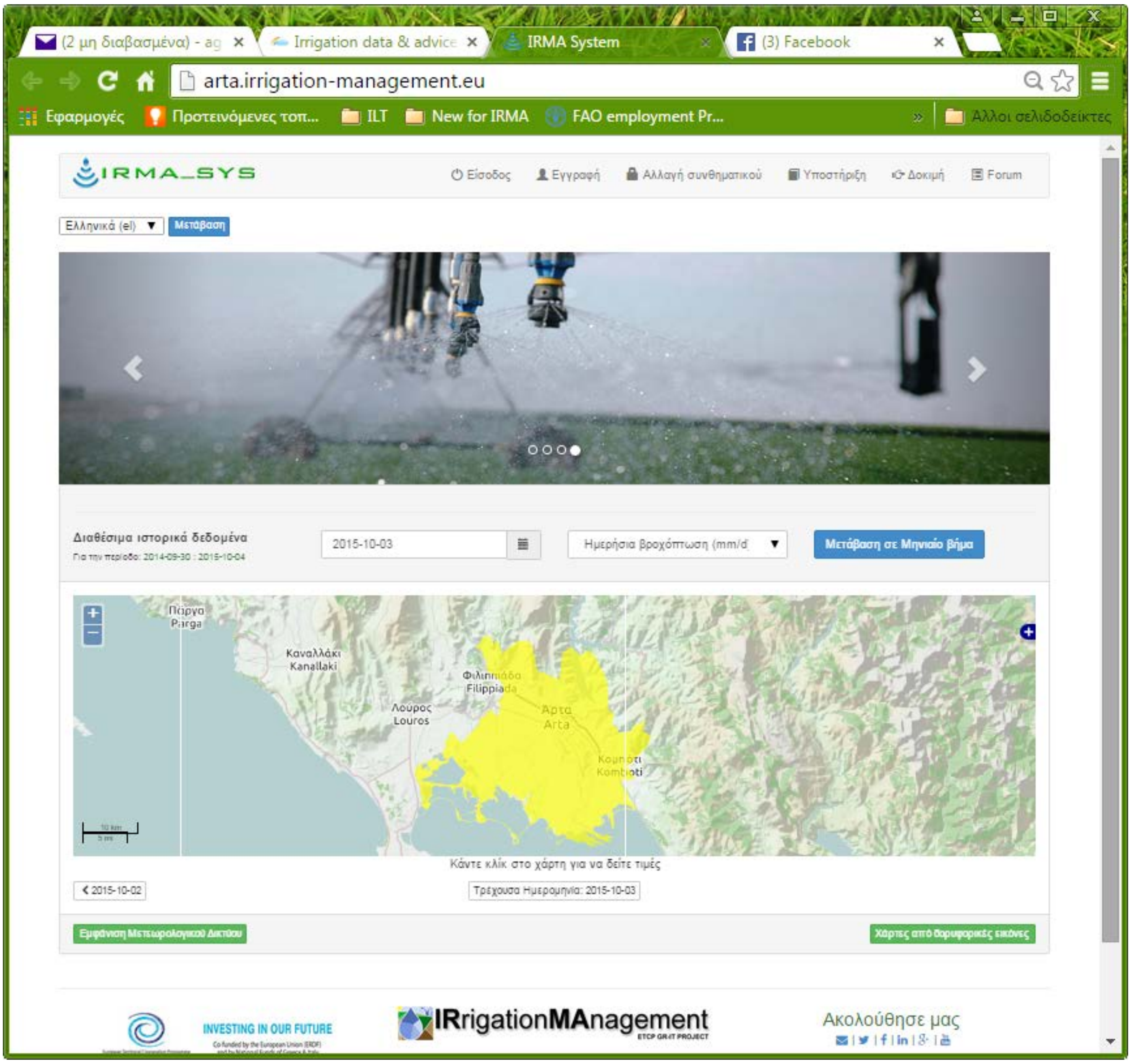


Fig. 8 Screen-shot of the front page of the service

Objectives

IRMA_sys (http://arta.irrigation-management.eu/) will provide irrigation related information and irrigation scheduling recommendations was developed in pilot level for the plain of Arta (Region of Epirus / Greece).

The objective of the present report is to present the first evaluation of the system.

In the framework of the evaluation, the service has been tested for the case of turfgrass during the 2015 irrigation period (CASE STUDIES 1 and 2). The fields that were used for the evaluation where located at the Kostakii Campus of the Technological Education Institute of Epirus. The reference treatment was an irrigation system equipped with a controller that used water budget periods.

Also two other case studies are presented, one of which regards a kiwi-fruits orchard (CASE STUDY 3) while the other a tangerine orchard (CASE STUDY 4). Both fields where located at the plain of Arta. For these cases the applied water during the summer-fall period of 2015 is compared to that proposed by IRMA_sys.

Meteorological conditions at Arta during the 2015 irrigation period

Calculated monthly reference evapotranspiration ETo and precipitation rates during the experimental period (2015) from NOA (2015) and relevant climatic parameters (HNMS, 2014) are presented in Fig. 9.

It is obvious that during 2015, ETo was very close to the climatic values, but 2015 was characterized by much more rain.

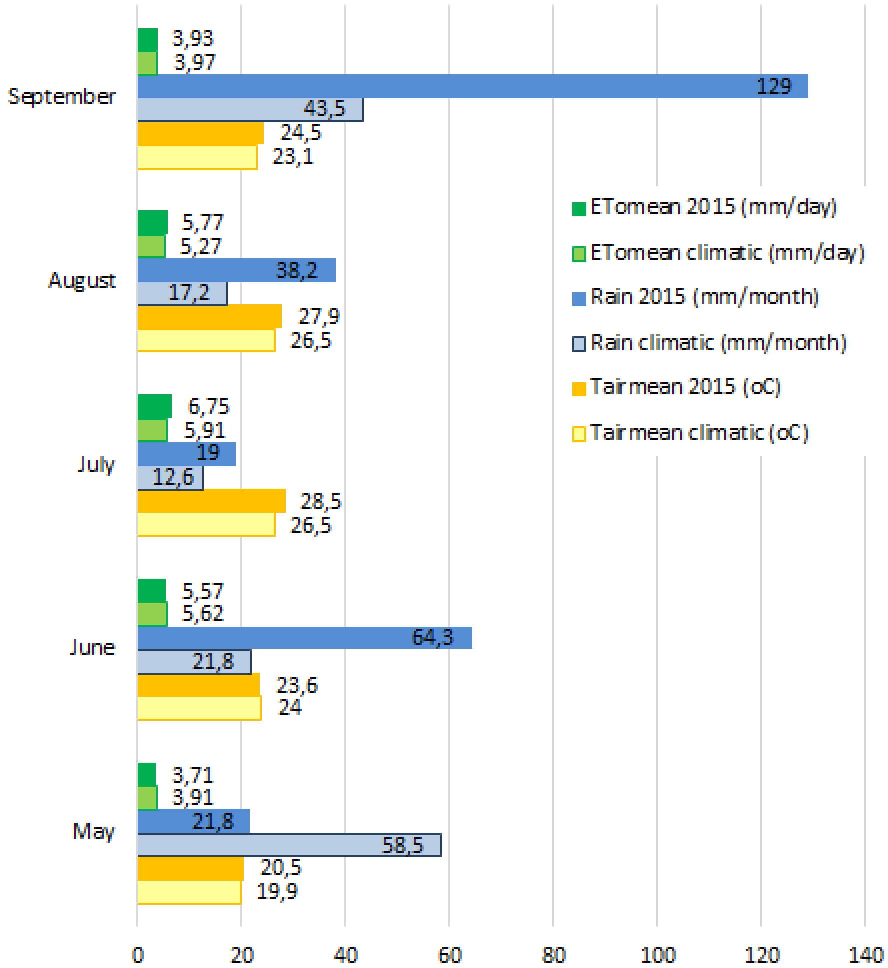


Fig. 9 Climatic (20y) and meteorological information (2015)

* Based on climatological data for Arta plain (HNMS, 2014); [a] ETL is the daily average reference evapotranspiration as calculated according to FAO paper 56 method; [b] R is the cumulative precipitation height.

CASE STUDIES 1 and 2: Irrigation of turfgrass

Materials and Methods

Location and climate

The evaluation was conducted during 2015 irrigation period at TEIEP Kostakii Campus, 7km SW of the city of Arta in Greece (Fig. 10; lat. 39^o 70' N, long. 20^o 56' E / WGS84). Arta's climate is of Mediterranean type with mild and rainy winters and hot and dry summers with occasional rain events.

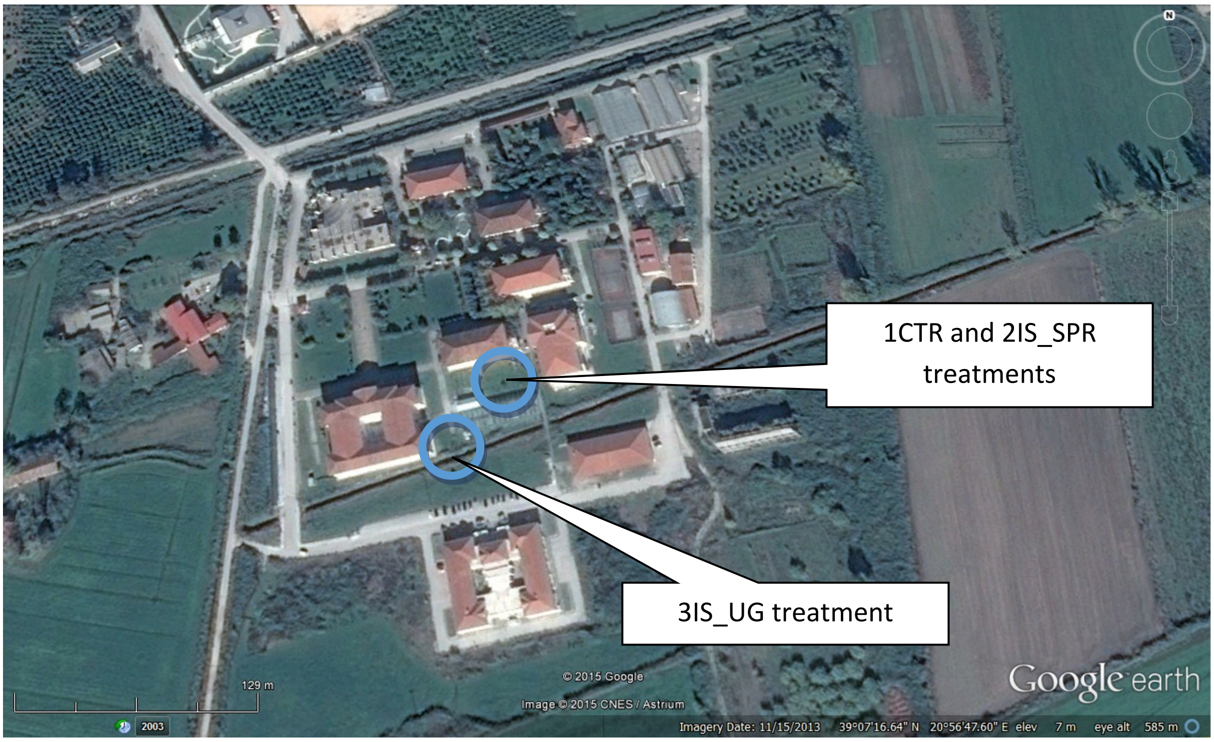


Fig. 10 Aerial view of TEIEP Kostakii Campus with indications of the treatments' location (GoogleEarth, 2015)

Treatments and experimental setup

The following treatments were applied:

- 1CTR: irrigation controller using water budget periods
- 2IS_SPR: sprinkler irrigation following recommendations from IRMA_sys
- 3IS_UG: underground drip irrigation following recommendations from IRMA_sys

Turfgrass was installed in containers of 2x2x0.22m. Each treatment was replicated 3 times.

Soil and water

Each plot was filled with gravel at a depth of 8 cm. Above the gravel layer, a uniformly mixed locally available soil (loamy sand, LS: 86.40% sand; 11.64% clay and 2.36% silt). The pH of the soil was 7.8 and the electrical conductivity 0.64 dS m^{-1}. According to the characteristic water retention curve (LAB023V Soil Moisture Equipment Corp, USA), field capacity (θFC) and permanent wilt point (θPWP) measured 15.30% and 7.10% respectively. The infiltration rate of the soil (IF) was found to be 22.30 mm h^{-1}.

Potable water having a pH of 7.1 and an electrical conductivity (EC) of 0.42 dS m^{-1} was used for irrigation.

Plant material

Festuca arundinaceae (Schreb.) sod (commercial name "Heraklis"; Hellasod, 2014) was made available by a Greek supplier. The selection of the turfgrass was basically made using market popularity criteria. According to the manufacturer (Hellasod, 2014), the selected turfgrass is strong against fungal diseases; it is suggested to be mowed almost every 7 days to 3-5cm (or 6cm for shady places). The sod was laid on April 10, 2014 in the framework of 2014 IRMA's experiments. Installation and establishment procedures were applied following the guidelines of the nursery (soil preparation, fertilization, initial irrigation, establishment period precautions and care etc.).

Mowing

From June 12th, the plots were mowed at a height of 4.5 cm every ten days using a Rotak37LI battery powered mower (Robert Bosch GmbH, DE (Bosch, 2014)). Clippings were removed from the site.

Measuring and calculation of evaluation parameters

Meteorological data

Meteorological data, namely air temperature and relative humidity (Tair, ^{o}C and RHair, %), solar radiation (RS, Wm^{-2}), wind speed (W ms^{-1}) and direction at 2m height as well as rain (R, mm), were recorded every 30 min by means of a nearby station (HOBO Weather Station, ONSET instruments, USA). These data were used for evapotranspiration (ET) calculations based on Allen et al. (1998).

IRMA_sys recommendations and data

IRMA_sys can send emails to each user that contain recommendations for the next 3 days period (Fig. 11). The frequency of this can be set by each user. The supervisor of the user (if any) also receives these emails. This function was available from the first week of July 2015.

Data for each field can be downloaded from the irrigation performance section. Data are available in CSV format and contain Date, Estimated Irrigation Water Amount (mm), Applied Irrigation Water Amount (mm) and Effective precipitation (mm). The file is named ##-performance.csv (## is the internal code of the field) and can be inserted in a spreadsheet following a number of steps (Fig. 12): Data; From Text; Delimited; delimiter: Tab and Comma; Column data format General and start for A1 cell. The latest is an indicative option, also have in mind that decimals will be separated using . so if , is what is actually used in the spreadsheet a relevant replacement has to be made).

Fig. 11 Typical notification e-mail

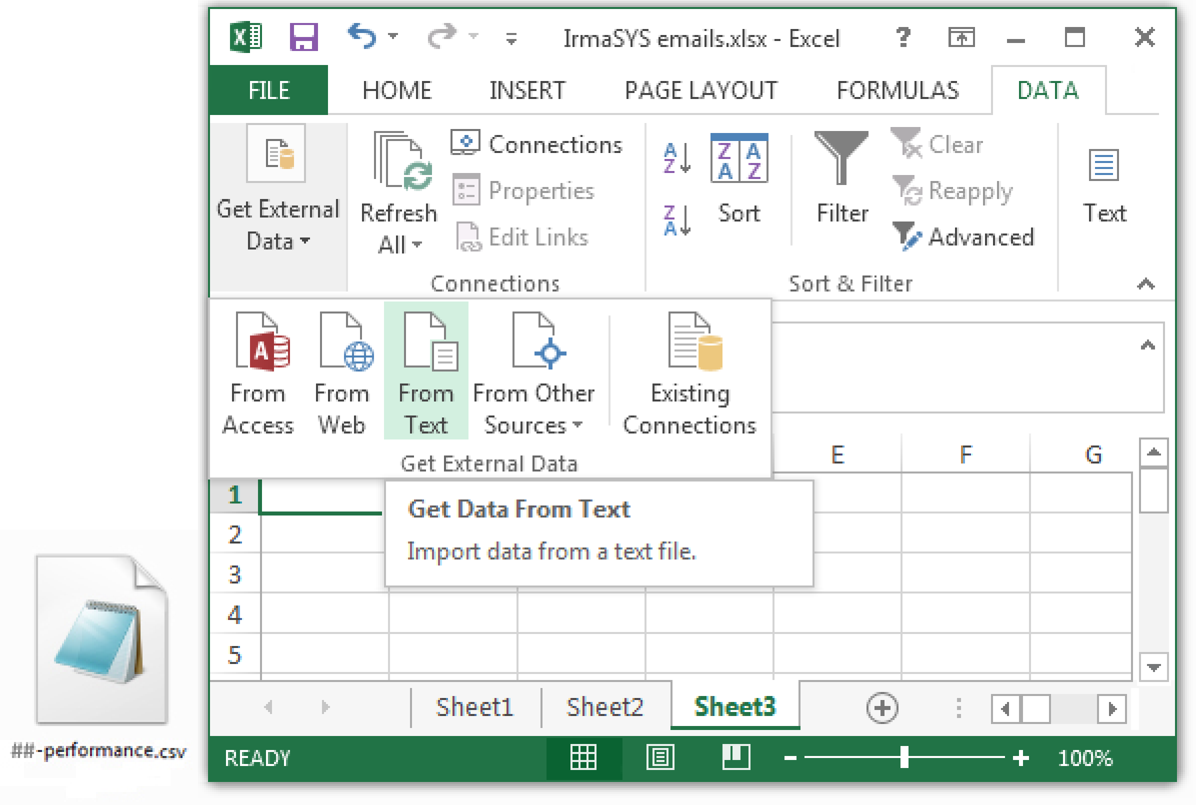


Fig. 12 Data file and way to insert it in spreadsheet

Soil moisture monitoring

Campbell (2013) stated that at least two sensors are needed to compute a reliable water balance: a shallower sensor to monitor root zone moisture and a deeper sensor to provide drainage loss data. McCready and Dukes (2011) on the other hand suggest the use of only one sensor placed vertically in order to measure the average moisture between 8 and 18cm.

The volumetric water content (VWC) of the soil was continuously monitored using EC-5 (Decagon Devices Inc., USA). This sensor has 2 prongs of 5cm length and use Frequency Domain Reflectometry (FDR) to measure VWC from 0 to 100%. According to the manufacturer (Cobos, 2008; Decagon Devices, 2012) the generic linear conversion equation for all mineral soil types with electrical conductivities from 0.1 to 10 dS m^{-1}, provide a ±0.03 m^3m^{-3} accuracy (for a maximum of approximately 60% VWC). This could be improved up to ±0.01 to ±0.02 m^3m^{-3} if calibrated (using linear or polynomial equations) for a specific soil (Cobos and Chambers, 2010; Decagon Devices, 2011 and 2012). In order to achieve this improvement, a relevant calibration was performed and a SWAT calibration was applied (IA, 2008b). Based on this calibration, a number of equations for converting the sensor output to actual moisture content are provided.

According to our analysis VWC (θ %v/v) for the given soil is given by:

a) $\theta = 8.5 \cdot 10^{-4} \cdot \text{RAW} - 0.48$

b) $\theta = 6.1 \cdot 10^{-4} \cdot \text{RAW} - 0.35$

c) $Y = 0.8238 \cdot X + 0.0646$

Eq. 1 EC-5 VWC equations: a) Decagon's generic equation for mineral soils; b) specific soil equation after laboratory calibration and c) SWAT response function for soils at 20°C

where RAW is the output from the Decagon data logger; X is the sensor output and Y the actual soil moisture

Soil specific calibration is not a very practical approach but it is necessary as the differences are considerable.

EC-5 sensors were placed vertically with the edges of its prongs at 10cm. The installation of the EC-5 sensors was made after the uniformity audit of the system and they were placed at areas that received irrigation amounts similar to the average value for each treatment.

The sensors were connected to Em50 dataloggers (Decagon Devices Inc., USA).

Measurement of water consumption

Measurement of the water consumption during the evaluation period was made using 1'' volumetric dry dial water meters (1L resolution) (Fig. 13). One meter was installed for each treatment, and the measurements were registered manually every six to eight days.

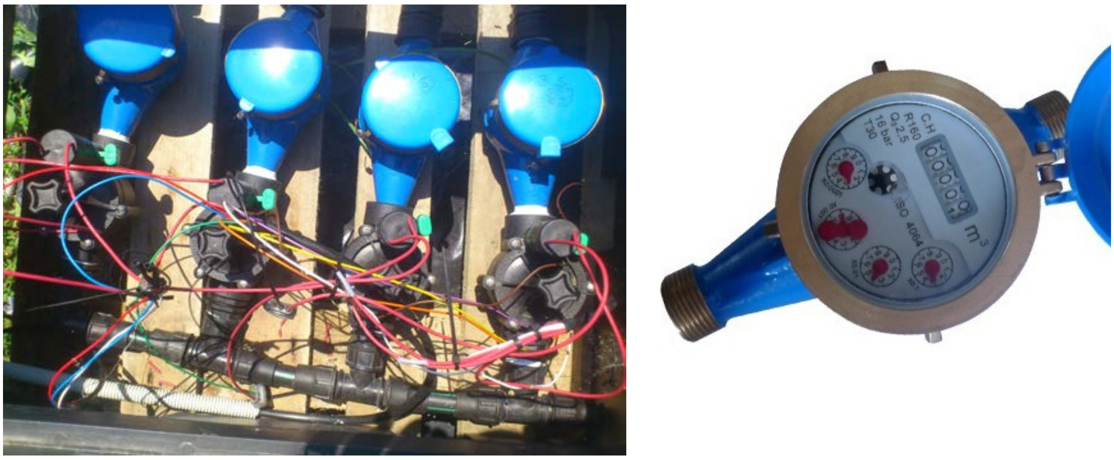


Fig. 13 Volumetric water meters (one valve box: 4 of the total 7 water meters that were installed)

Turfgrass canopy growth measurements

In order to perform growth evaluation, turfgrass cuttings were collected (using a vacuum) from each replication (sampling was made using a 0.3x0.3x0.045m metal frame; Fig. 14) before each mowing event, weighed (fresh weight), dried at 70°C for 48h and then weighed again in order to obtain the dry weight.

Fig. 14 Sample cuttings equipment and field procedure

Reflectance measurements for qualitative evaluation of turfgrass

Turfgrass quality is typically evaluated by using panel scores (1-9) which include canopy color, density and texture (National Turfgrass Evaluation Program (NTEP) / Morris and Shearman, 1998). Canopy spectral reflectance (CSR) provides an objective means to evaluate turfgrass quality, but the results can be confounded by differences in reflectance among species or cultivars (Bremer et al., 2011).

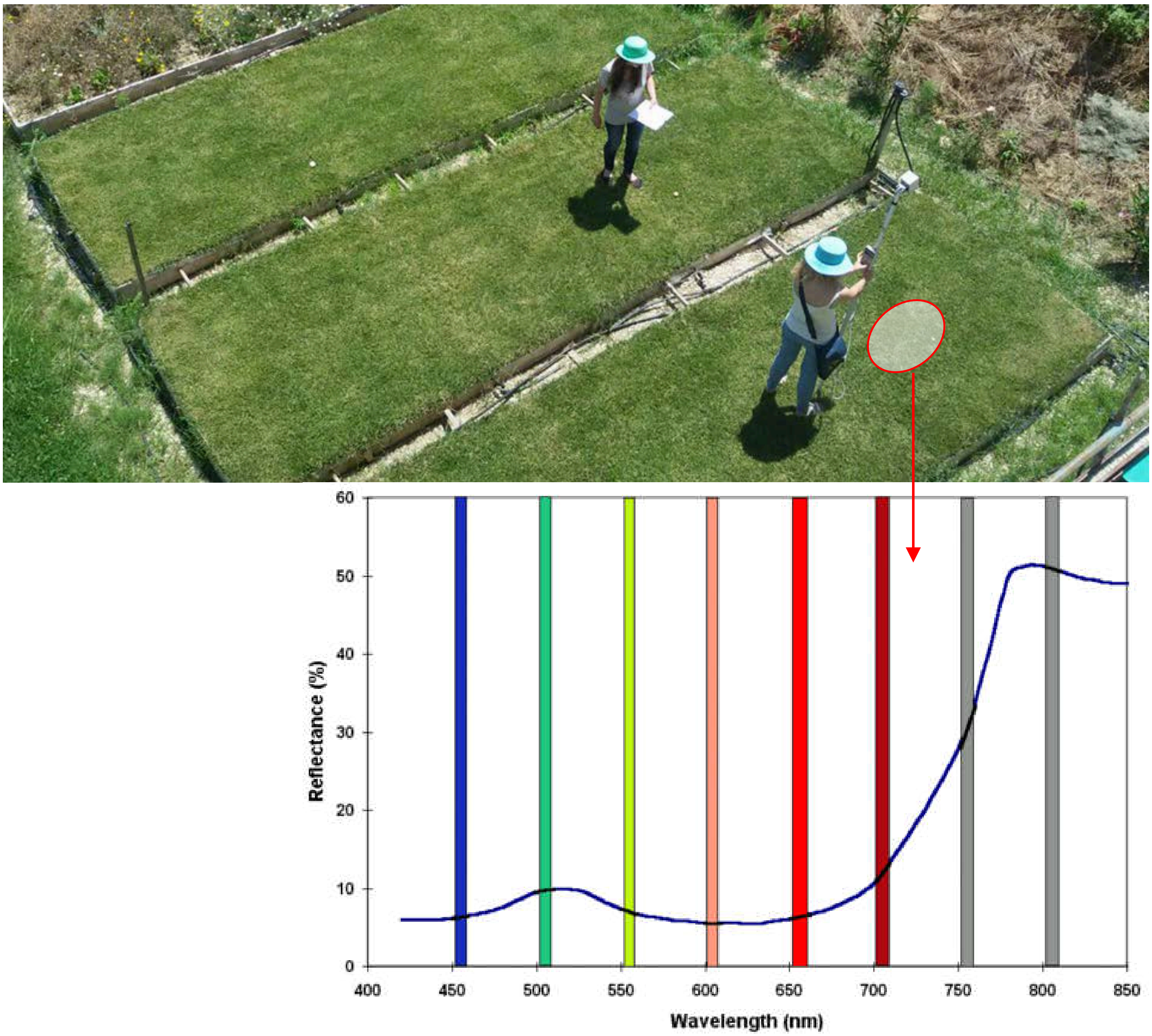


Fig. 15 Canopy reflectance measurement using CropScan (with a shape indicating the measuring area) and typical reflectance spectrum over turfgrass

In the framework of the present work, CSR was measured using a hand-held multispectral radiometer (model MSR87, CropScan, USA) which provides reflectance data at 8 band widths (10nm) centered on 460, 510, 560, 610, 660, 710, 760 and 810nm. Reflectance measurements over the turfgrass canopy were collected with the sensor placed at 1 m above ground level which according to the manufacturer corresponds to a circular measuring area of 0.5m diameter).

Reflectance was measured 3 days after each mowing event around solar noon; unless prevented by poor weather conditions, in which case measurements were made the following day. Also there was precaution for a 3 hour time period from the last irrigation event. All plots were fully vegetated and thus, soil background effects were considered negligible.

A Photochemical Reflectance Index (PRI) for estimating light use efficiency (Gamon et al., 1997) and a Normalised Difference Vegetation Index (NDVI) for estimating canopy phenology (Sönmez et al., 2008) were used for quality evaluation of each treatment in comparison to the reference one.

The indices were calculated as: PRI ((R_X - R_{Ref}) / (R_X + R_{Ref}))) equals to (R_{560} – R_{510}) / (R_{560} + R_{510}) and NDVI ((R_{NIR} – R_{Red}) / (R_{NIR} + R_{Red})) equals to (R_{810} – R_{660}) / (R_{810} + R_{660}), where R denotes reflectance at the specified wavelength, X is a wavelength in the absorbance of xanthophyll pigments spectral region; Ref is the reference wavelength for PRI measurements, NIR is the near infrared and Red is the Red region of the spectrum. The measurements were made around solar noon.

Statistical analysis methods

Descriptive statistical parameters and T-student tests (at 95% confidence level) were performed to analyse the obtained data by using MS-Excel (Microsoft Corp, USA). Average values are followed by the standard error values in parentheses. Means where compared using Student’s t-test, at a confidence level (CL) of 95%.

Case study 1 Turfgrass irrigated using sprinkler irrigation

Characteristics of the sprinkler irrigation system

For the 1CTR and 2IS_SPR all replications were irrigated using a head-to-head square pattern sprinkler system. Irrigation was made using 8 Hunter 8A Pro spray sprinkler heads. All heads were placed on special adaptors at the outer face of each container. According to the technical specifications (Hunter, 2012) these nozzles were expected to have a flow 1.09lpm for the 90^o and 2.13lpm for 180^o (radius 2.4m which was reduced to 2m and theoretical precipitation rate (PR) 64,40mm h^{-1}) when operated at 2 bar. The total flow for each of the 2x6m systems (1CTR and 2IS_SPR). A 120 mesh net filter was placed after the systems manual valve. One inch (1'') control valves and 1'' water meters where used for water flow control and measurement of each treatment (one valve per treatment plus one for the backup) and a 2.1 bar outlet pressure regulator was installed after each valve.

The lower quarter distribution uniformity of the system (DUq), according to the audit procedures of IRMA Deliverable 5.1.6.; was found to be 73% (±3%) and 71% ((±2%) [1] for 1CTR and 2IS_SPR respectively.

1CTR reference turfgrass sprinkler irrigation treatment

This treatment was considered to match typical “good” practice of local turf managers and homeowner’s.

Climatic irrigation schedule

According to ELOT (2009), the frequency and duration of irrigation events is based on turfgrass type, the soil, the climate and the season. For Greece, the average needs during summer and for typical soils are about 5-6 mm d^{-1}.

According to the sod manufacturer (HellaSod, 2014), during summertime, this specific turfgrass should be irrigated every 2-3 days with the goal to receive 50-70mm per week (7-10mm d^{-1}, considering the soil type and the climate).

The estimation of water requirements was based on the methodology proposed in FAO-Paper 56 (Allen et al., 1998) using the available (T, RH, wind speed) historical climatic data for the area (20 years averages; HNMS, 2014).

For the calculation of reference evapotranspiration (ETo) the Hargreaves method (Allen et al., 1998), corrected for wind speed was used. Following UCCE and CDWR (2000) recommendations, the coefficients of species (ks), density (kd) and microclimate (kmc) where estimated to be about 0.8, 1 and 1 respectively.

[1] Standard error (4 measurements were made during the evaluation period)

Table 1 Calculation of reference evapotranspiration (ETo) using climatic data and turfgrass landscape evapotranspiration (ETL) using estimated landscape coefficients (KL=0.8)

Month	ETo (mm day^{-1})	ETL (mm day^{-1})	Period characterisation
April	3.45	2.76	cool
May	4.69	3.75	
June	5.62	4.50	warm
July	5.91	4.73	
August	5.27	4.22	
September	3.97	3.18	cool
October	2.52	2.01	

According to Table 1, the irrigation period was sectioned in two parts:

- cool period: April-May and September-October and
- warm period: June-August

April and October even if they have a potential to be included in the irrigation period, this is very small due to rains that in most years cover the irrigation needs of turfgrass in the area.

Following the procedures proposed by Brouwer et al. (1989) and Melby (1995) as well as the advices of Huang (2006) the following generic - climatic irrigation schedule was estimated (Table 2):

- one irrigation event every 2nd day
- 15 min run time per irrigation event
- water budget at 60% during the cool part of the irrigation period

Table 2 Irrigation schedule

Month	Q L min^{-1}	PR mm h^{-1}	WT min week^{-1}	RTmax min	FT number	FP number	RT min
April	12.88	64.40	30	22	1.36	3.5	8.57
May	12.88	64.40	41	22	1.86	3.5	11.71
June	12.88	64.40	49	22	2.23	3.5	14.00

Month	Q L min^{-1}	PR mm h^{-1}	WT min $week^{-1}$	RTmax min	FT number	FP number	RT min
July	12.88	64.40	51	22	2.32	3.5	14.57
August	12.88	64.40	46	22	2.09	3.5	13.14
September	12.88	64.40	35	22	1.59	3.5	10.00
October	12.88	64.40	22	22	1.00	3.5	6.29

Q: station flow rate; PR: precipitation rate; WT: necessary system run time; RTmax: maximum allowable duration of an irrigation event; FT: theoretical estimation of weekly irrigation events number; PT: decided practical number of weekly irrigation events; RT: irrigation event duration (run time).

Actual irrigation schedule

The irrigation schedule that will be applied is based on the climatic one but is expected to be calibrated to match the actual system performance in field and the meteorological conditions of each irrigation period. The experience from running the same system in 2014 was capitalized in adopting the following actual schedule:

- The irrigation system was turned on in spring and then off in late fall.
- The irrigation period was divided in two sections, following an expected (based on historical climatic data) changes in ETo: a) cool period: April-May and September-October and b) warm period: June-August.
- The applied schedule was the following:
    - From 18/5/2015 (initiation), one irrigation event every 2nd day, start time at 9:05 in the morning, 8min run time per irrigation event, water budget at 60% during the cool part of the irrigation period (until 31/5)
    - At 9/6 the duration was shifted to 9min and the Water Budget was turned to 100% while on 19/6 the duration was changed to 11min
    - At 10/9 the Water Budget was turned to 60%.

The schedule was applied using an Orbit sprinkler timer Model # 94881 (Orbit, 2014). The timer has a water budget feature which was used to adjust for seasonal watering demands. Instead of reprogramming the timer, the “Water Budget Mode” enables easy adjustments to watering duration by ten percent increments from 10%-200%. For example, a budget percentage set at 60% will alter a 10-minute preset watering duration to 6 minutes.

Fig. 16 Orbit sprinkler timer

2IS_SPR turfgrass sprinkler irrigation treatment

Information regarding the soil properties (as resulted after a relevant analysis), the irrigation system (spray sprinklers) and the plant material (a type of tall fescue) has been provided above.

Treatment field characteristics

The field had the following characteristics:

Table 3 Characteristics of 2IS_SPR field

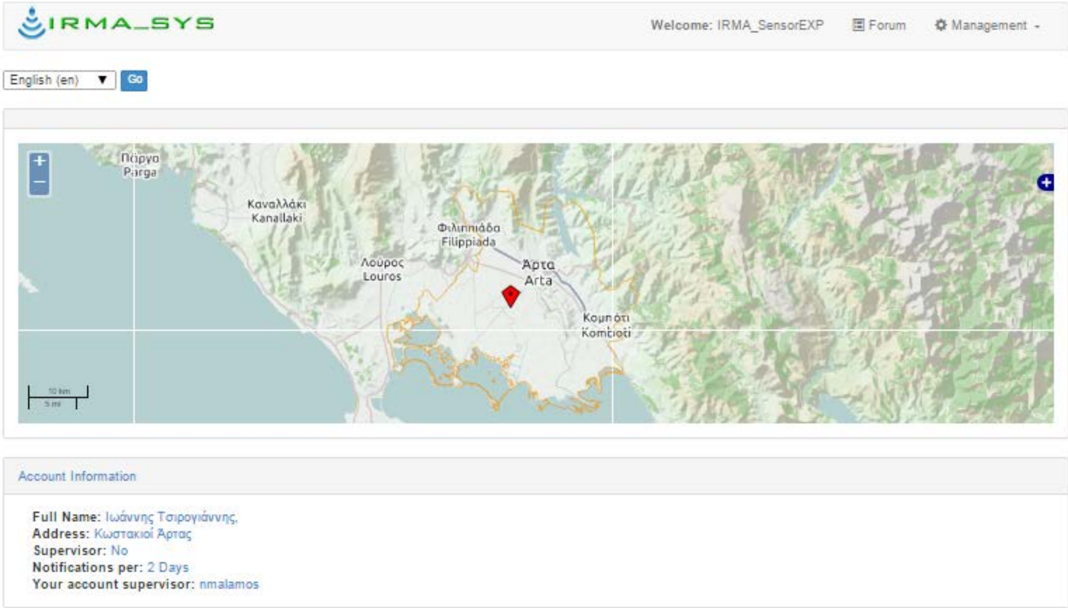
Field name	Sensors Experiment TEIEP Kostakii Campus
Irrigated Field Area (m^2)	12 (total of all replications)
Longitude (WGS84)	20.94591
Latitude (WGS84)	39.12114
Crop Type	Turf grass – cool season
Irrigation Type	Sprinkler irrigation

Custom parameters were used regarding the crop, the soil and the system:

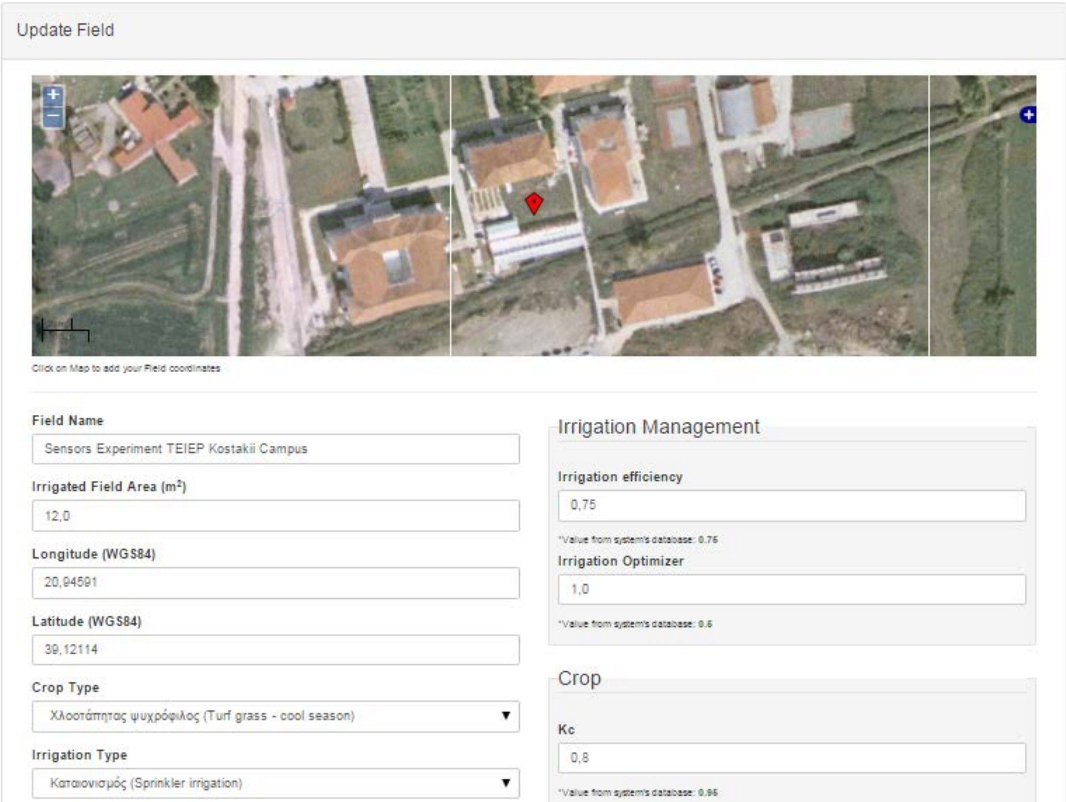
Table 4 Parameters of 2IS_SPR field

Parameter category	Parameter	Default system value (value from the system's database)	Custom parameter
System	Irrigation efficiency	0.75	0.75
	Irrigation optimizer	0.60	1.00
Plant	Kc	0.95	0.80
	Maximum Allowable Depletion	0.40	0.50
	Estimated root depth (max)	1.00	0.20
	Estimated root depth (min)	0.50	0.20
Soil	Field Capacity	0.39	0.15
	Permanent Wilting Point	0.10	0.07
	Soil moisture at saturation	0.50	0.35

Soil characteristics differ significantly from those proposed by the system (which are based on a top soil map of the area) as a specially selected for the case soil mixture was brought to the place and installed at the field. From the soil characteristics, infiltration rate is not used by the system as it is a design parameter which is used to select the outlets and a scheduling parameter that is used to define limits regarding the duration of irrigation events.



a



b

Fig. 17 2IS_SPR field overview screen-shots

Notification regarding estimated field condition and the need for irrigation was selected to be sent every 2 days (the message was sent at 5:00 in the morning).

Evaluation period and system data

The evaluation period spanned from April to September 2015. 43 irrigation events were applied from April 24th to September 7th.

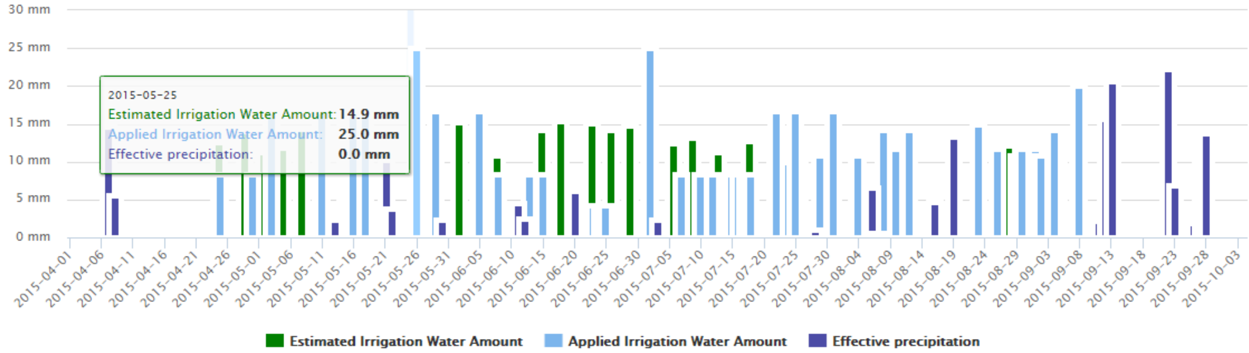


Fig. 18 Irrigation performance diagram as provided by the service for 2IS_SPR

According to IRMA_sys, the following facts were registered for the evaluation period:

- Total Effective Precipitation: 179.7 mm
- Total Estimated Irrigation Water Amount: 423.2 mm
- Total Applied Irrigation Water Amount: 518.9 mm
- Percentage difference: +23.0 %

Table 5 presents the complete list of notifications that the system send during the evaluation period. As already mentioned, this function was available from the first week of July 2015.

Table 5 Notification reports for 2IS_SPR

Date of notification report	for the period	Recommended volume (mm)	Recommended volume (m^3)	to be applied on
7/7/2015	07/07 -09/07/15	32.23		08/7/2015 12:00
9/7/2015	09/07 - 11/07	32.40		09/7/2015 12:00
11/7/2015	11/07 - 13/07	16.06		12/7/2015 12:00
13/7/2015	13/07 - 15/07	16.17		14/7/2015 12:00
15/7/2015	15/07 - 17/07	16.04		16/7/2015 16:00
17/7/2015	17/07 - 19/07	16.03		18/7/2015 16:00
19/7/2015	19/07 - 21/07	does not need to be irrigated		
21/7/2015	21/07 - 23/07	15.36		21/7/2015 00:00
21/7/2015	21/07 - 23/07	11.07		22/7/2015 10:00
23/7/2015	23/07 - 25/07	11.06		24/7/2015 12:00
25/7/2015	25/07 - 27/07	does not need to be irrigated		
27/7/2015	27/07 - 29/07	10.89	0.13	28/7/2015 11:00

Date of notification report	for the period	Recommended volume (mm)	Recommended volume (m^3)	to be applied on
29/7/2015	29/07 - 31/07/2016	does not need to be irrigated		
31/7/2015	31/07 - 02/08	11.29	0.14	01/8/2015 17:00
2/8/2015	02/08 - 04/08	11.06	0.13	03/8/2015 12:00
4/8/2015	04/08 - 06/08	10.68	0.13	04/8/2015 20:00
6/8/2015	06/08 - 08/08	11.32	0.14	07/8/2015 17:00
8/8/2015	08/08 - 10/08	10.92	0.13	8/8/2015 14:00
10/8/2015	10/08 - 12/08	10.75	0.13	10/8/2015 15:00
12/8/2015	12/08 - 14/08	11.02	0.13	13/8/2015 16:00
14/8/2015	14/08 - 16/08	10.69	0.13	14/8/2015 16:00
16/8/2015	16/08 - 18/08	11.21	0.13	17/8/2015 15:00
18/8/2015	18/08 - 20/08	does not need to be irrigated		
20/8/2015	20/08 - 22/08	does not need to be irrigated		
22/8/2015	22/08 - 24/08	does not need to be irrigated		
23/8/2015				
24/8/2015	24/08 - 26/08	10.85	0.13	25/8/2015 13:00
26/8/2015		10.88	0.13	26/8/2015 18:00
28/8/2015	28/08 - 30/08	10.90	0.13	28/8/2015 10:00
28/8/2015	28/08 - 30/08	11.32	0.14	29/8/2015 16:00
30/8/2015	30/08 - 01/09	11.29	0.14	30/8/2015 16:00
1/9/2015	01/09 - 03/09	10.88	0.13	01/9/2015 18:00
3/9/2015	03/09 - 05/09	11.40	0.14	03/9/2015 13:00
5/9/2015	05/09 - 07/09	10.84	0.13	06/9/2015 16:00
7/9/2015	07/09 - 09/09	13.20	0.16	07/9/2015 01:00
9/9/2015	09/09 - 11/09	does not need to be irrigated		
11/9/2015	11/09 - 13/09/2016	does not need to be irrigated		
13/9/2015	13/09 - 15/09	does not need to be irrigated		
15/9/2015	15/09 - 17/09	does not need to be irrigated		
17/9/2015	17/09 - 19/09	does not need to be irrigated		
19/9/2015	19/09 - 21/09	does not need to be irrigated		
21/9/2015	21/09 - 23/09	does not need to be irrigated		
23/9/2015	23/09 - 25/09	does not need to be irrigated		
25/9/2015	25/09 - 27/09	does not need to be irrigated		
27/9/2015	27/09 - 29/09	does not need to be irrigated		
29/9/2015	29/09 - 01/10	does not need to be irrigated		

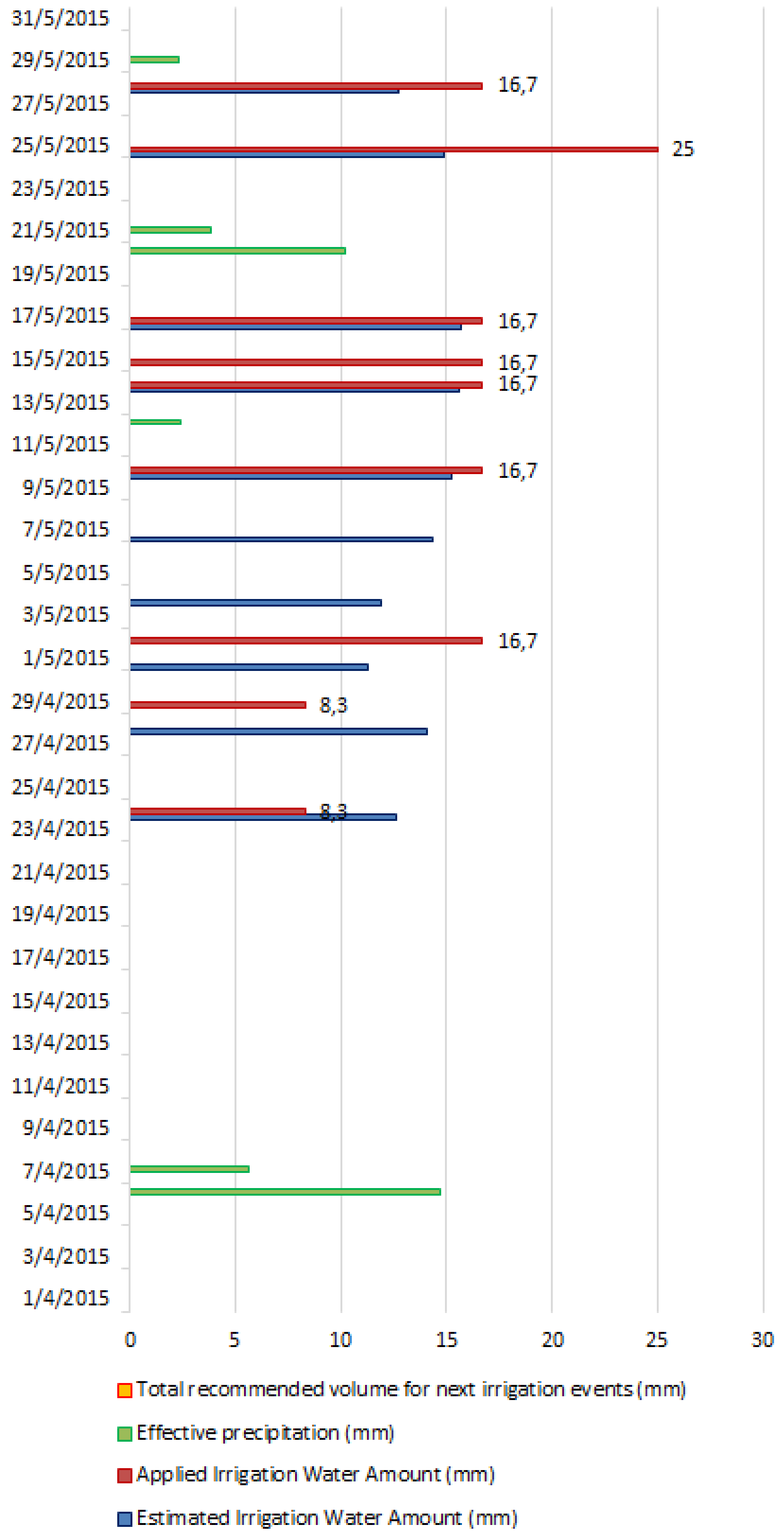


Fig. 19 System data for 2IS_SPR during April and May 2015

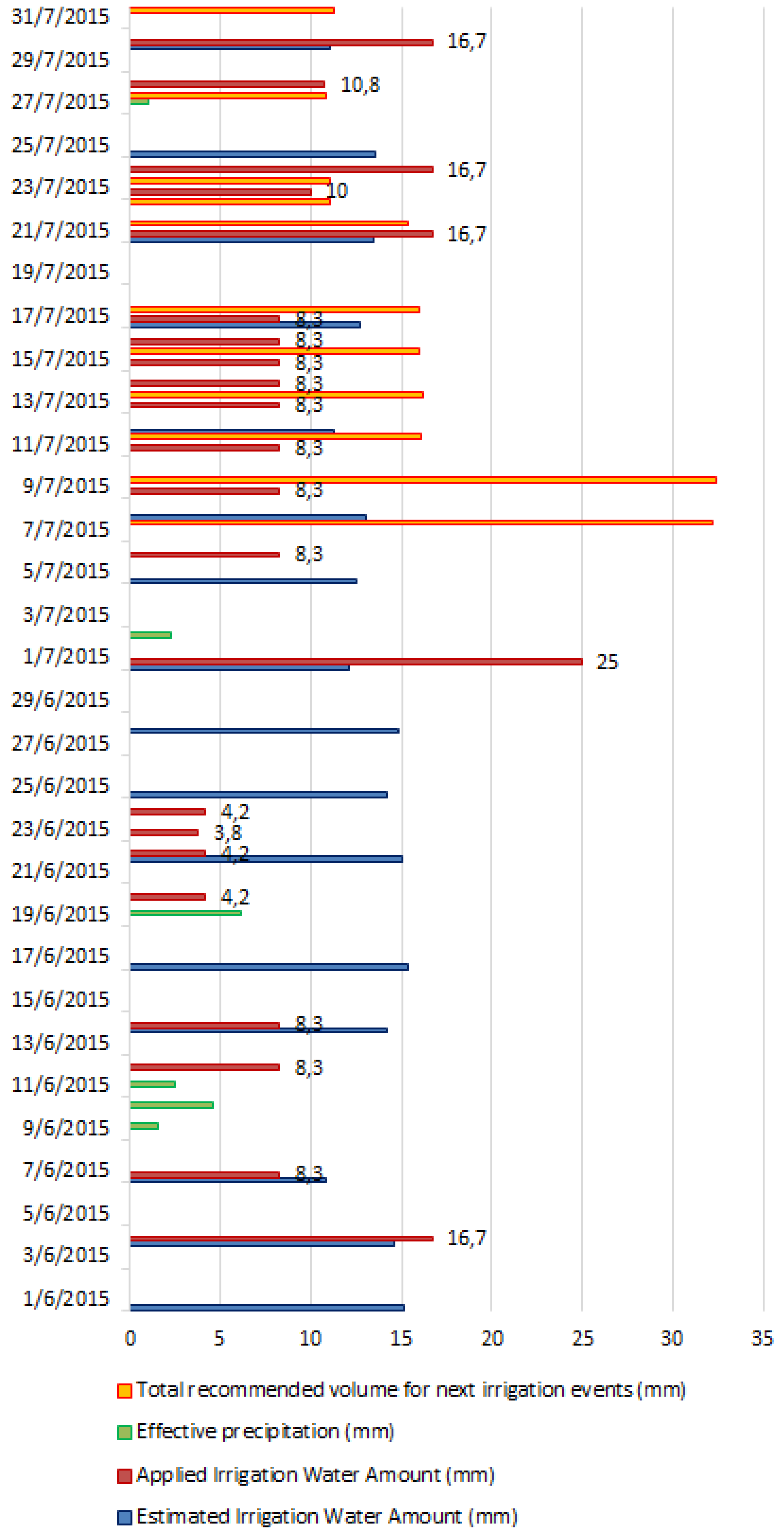


Fig. 20 System data for 2IS_SPR during June and July 2015

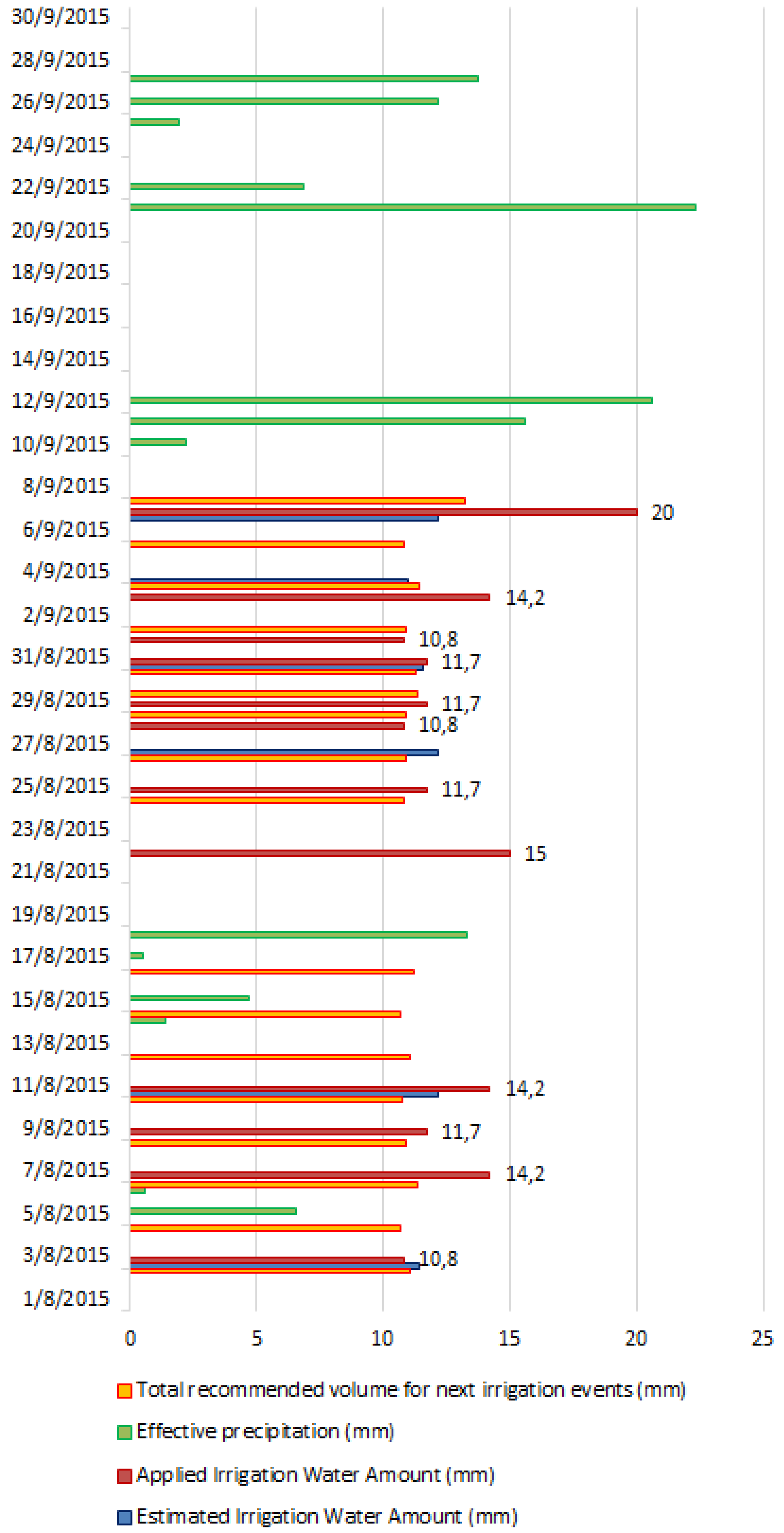


Fig. 21 System data for 2IS_SPR during August and September 2015

Fig. 19, Fig. 20 and Fig. 21 provide an image regarding the operation values of the system from April 1st up to the end of September 2015.

Soil moisture comparison

As it is presented in Fig. 22, soil moisture in both treatments was generally kept inside the limits of available water, but it is obvious that it was at a lower lever for IRMA_sys treatment (2IS_SPR).

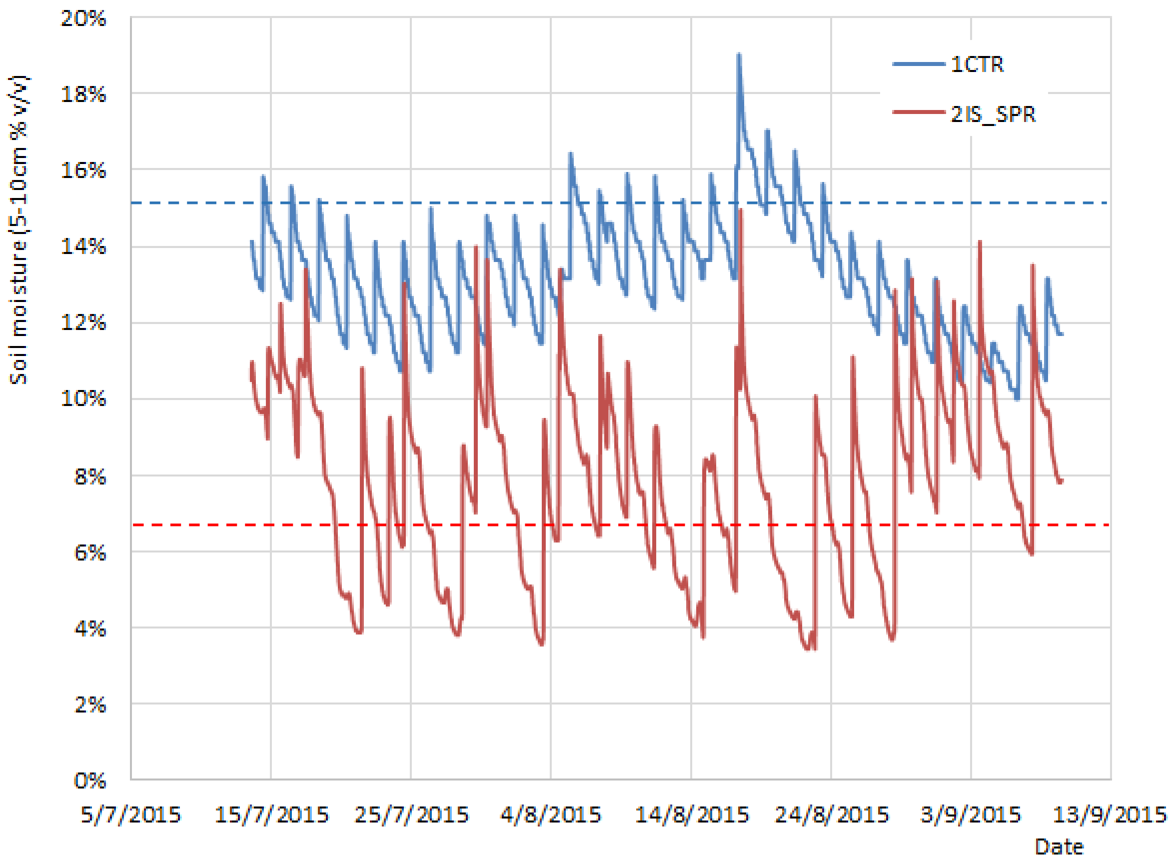


Fig. 22 Soil moisture for the two treatments, 1CTR and 2IS_SPR (blue line, --- FC level; red horizontal line, --- PWP level)

Irrigation water consumption comparison

Measuring irrigation water consumption has been the most important part of this case study. Of course the result of this comparison should also be used in conjunction with the qualitative comparison in order to come to a conclusion regarding the efficiency of the system.

Fig. 23 shows the cumulative water consumption for the two treatments. A third parameter, the theoretically expected irrigation needs (estimated as the landscape evapotranspiration for 2015 divided by the application efficiency minus the effective rainfall for 2015) is also presented in the same diagram.

For the evaluation period, 2IS_SPR consumed 12.28% and 26.43% less water when compared to the (ETL/IE)-Reff cummulative (mm) parameter and the reference 1CTR treatment respectively.

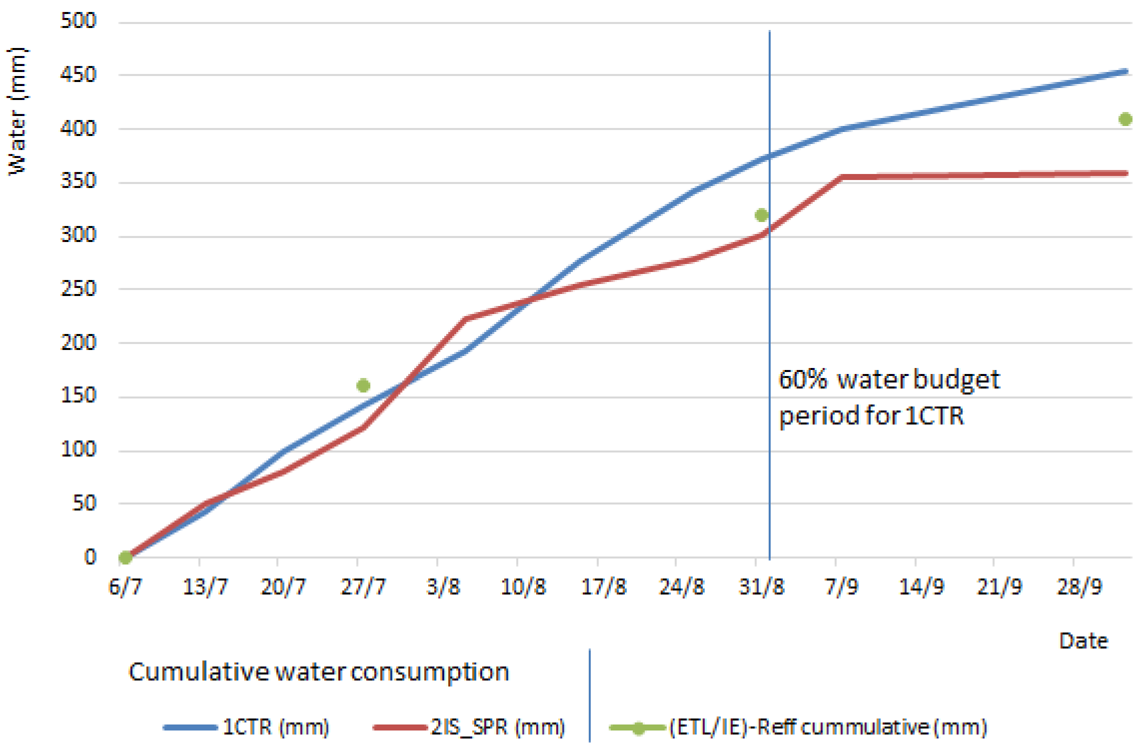


Fig. 23 Water consumption for the two treatments (1CTR and 2IS_SPR)

Turfgrass growth comparison

Fig. 24 resents the evolution of the aerial part growth. The statistical analysis revealed that the results for the two treatments were not significantly different as determined by Student's t-test (CL 95%).

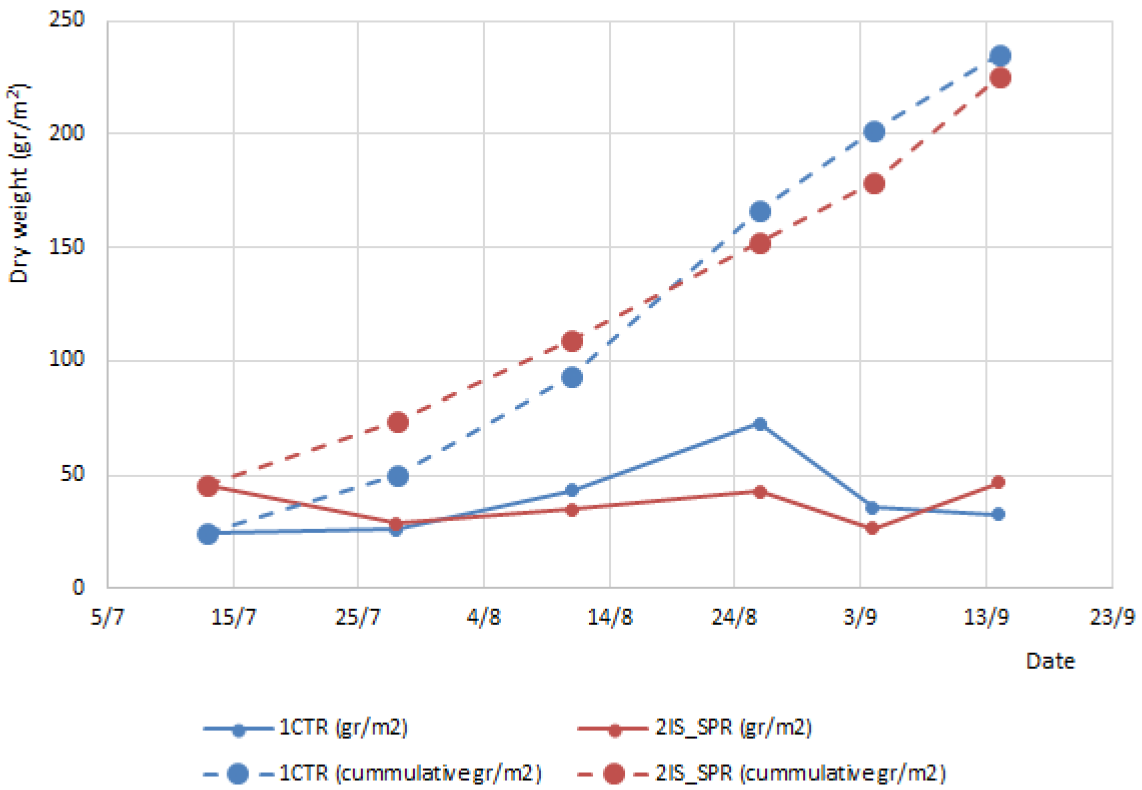


Fig. 24 Evolution of the aerial part growth for 1CTR and 2IS_SPR treatments

Turfgrass quality comparison

Concerning turfgrass quality, the results for both PRI (which is mainly linked to the photosynthetic activity) and NDVI (which is mainly linked to the canopy density) indices are presented in Fig. 25 and Fig. 26 respectively.

The statistical analysis revealed that both results for the two treatments were significantly different as determined by Student's t-test (CL 95%). This means that their differences could be attributed to the differentiation factor which is the provided quantity of water.

Bremer et al. (2011) states that for tall fescue, a good NDVI value is expected to about 0.85; while a value that represents a medium quality situation is between 0.75 and 0.80.

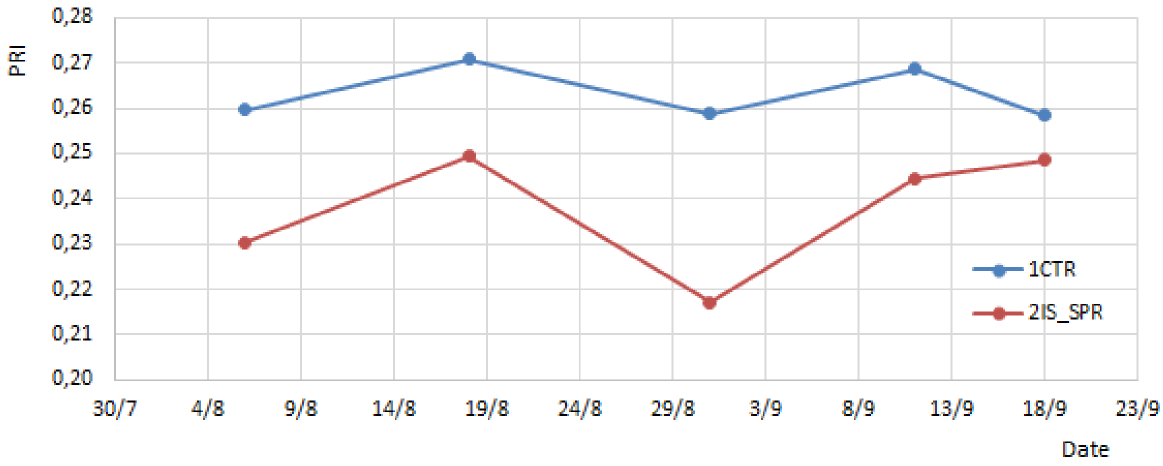


Fig. 25 PRI evolution for 1CTR and 2IS_SPR treatments (PRIcropscan = (R560 - R510) / (R560+ R510))

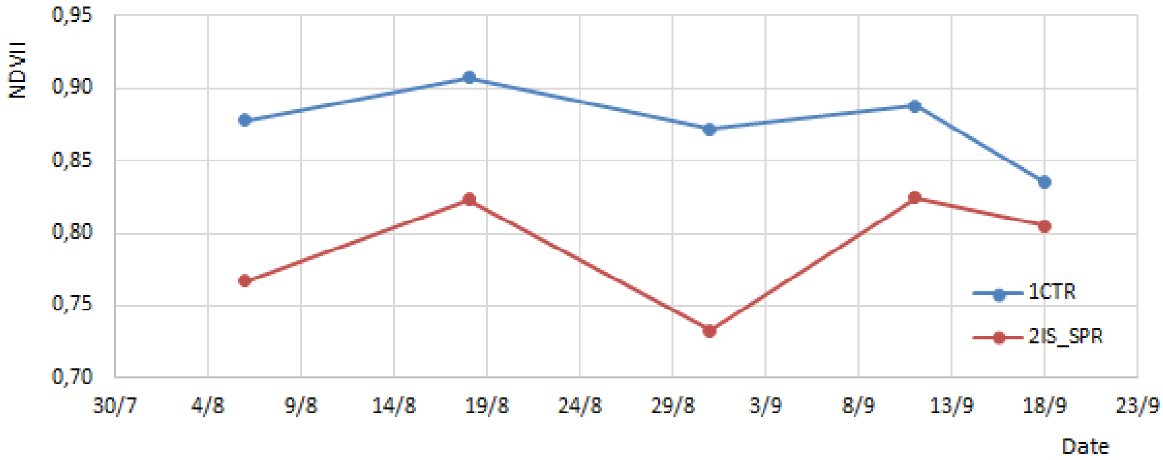


Fig. 26 NDVI for the 1CTR and 2IS_SPR treatments (NDVIcropscan = (R810 - R660) / (R810+ R660))

Case study outcomes

The IRMA_sys 2IS_SPR) resulted in much less water consumption than the reference (1CRT) treatment (-26.43%). A result of that was that soil moisture was kept in lower –still inside the available water zone- levels at 1IS_SPR treatment. This fact did not affected the growth of the aerial part of the grass in terms of clipping dry weight but resulted in differences regarding reflectance indices the provide information for color and density evaluation. Still, at least for NDVI, the values of 1IS_SPR are inside the zone of medium quality. The results can be evaluated as promising and they indicating that with proper calibration there is great potential to save water and keep very good quality too. A comparison of a number of treatments, having different set of parameters for the field would be of great value. Also a comparison against commercial sensor solutions would be very interesting.

Case study 2 Turfgrass irrigated using underground drip irrigation

2IS_UG turfgrass subsurface drip irrigation treatment

This case study concerned the same soil type and plant material as the previous one, it was located in the same experimental farm of TEI at Kostakii but there were differences regarding the irrigation system (subsurface drip irrigation in this one instead of sprinkler irrigation) and the schedule. Information regarding the soil properties (as resulted after a relevant analysis) and the plant material (a type of tall fescue) has been provided in the relevant sections above.

Characteristics of the underground drip irrigation system

This treatment was irrigated using a subsurface micro-irrigation system which was installed at a depth of 7cm. Pressure compensated driplines (Netafim Ø17, 1.6lph@0.30m) were used It must be noted that the suggested by the manufacturer anti-root chemical filter, to protect the emitter against root intrusion, was not installed. The lateral spacing of driplines was 0.35m. The system's precipitation rate was $18mmh^{-1}$.

Screen line filters (mesh 120) were placed in order to prevent drippers' clogging. Additionally air vacuum relief valves were placed at the highest point of each zone in order to allow the flow of the air out of the driplines during irrigation and flush valves were placed at the lowest end point of every zone drove the excess of water out of the driplines after the irrigation event had finished.

Irrigation schedule for the reference treatment (1_1C)

The irrigation schedule applied on reference treatment was estimated following the procedures proposed by Brouwer et al. (1989) and Melby (1995) as well as the advices of Huang (2006). The following generic - climatic irrigation schedule was estimated. Practically the applied irrigation system is summarized as:

- One irrigation event everyday
- 24 min run time per irrigation event
- water budget at 100% during the experimental period

Characteristics and irrigation schedule of the IRMA_sys treatment (1_2)

The experimental design included a Control treatment (reference treatment) with three replications and an IRMA_sys treatment which had 6 replications. The experimental field had the following characteristics:

Table 6 Characteristics of 2IS_UG field

Field name	IRMASys Experiment TEIEP Kostakii Campus
Irrigated Field Area (m^2)	36 (total of all replications of the two treatments)

Longitude (WGS84)	20,94551
Latitude (WGS84)	39,12086
Crop Type	Turf grass – cool season
Irrigation Type	Subsurface drip irrigation

Fig. 27 General view of the treatment area

Custom parameters were used regarding the crop, the soil and the system (Table 7).

Table 7 Parameters of 1_2 field

Parameter category	Parameter	Default system value (value from the system's database)	Custom parameter
System	Irrigation efficiency	0.95	0.95
	Irrigation optimizer	0.5	1.00
Plant	Kc	0.95	0.80
	Maximum Allowable Depletion	0.40	0.40
	Estimated root depth (max)	1.00	0.20
	Estimated root depth (min)	0.50	0.20
Soil	Field Capacity	0.39	0.15
	Permanent Wilting Point	0.10	0.07
	Soil moisture at saturation	0.50	0.38

Soil characteristics differ significantly from those proposed by the system (which are based on a top soil map of the area) as a specially selected for the case soil mixture was brought to the place and installed at the field.

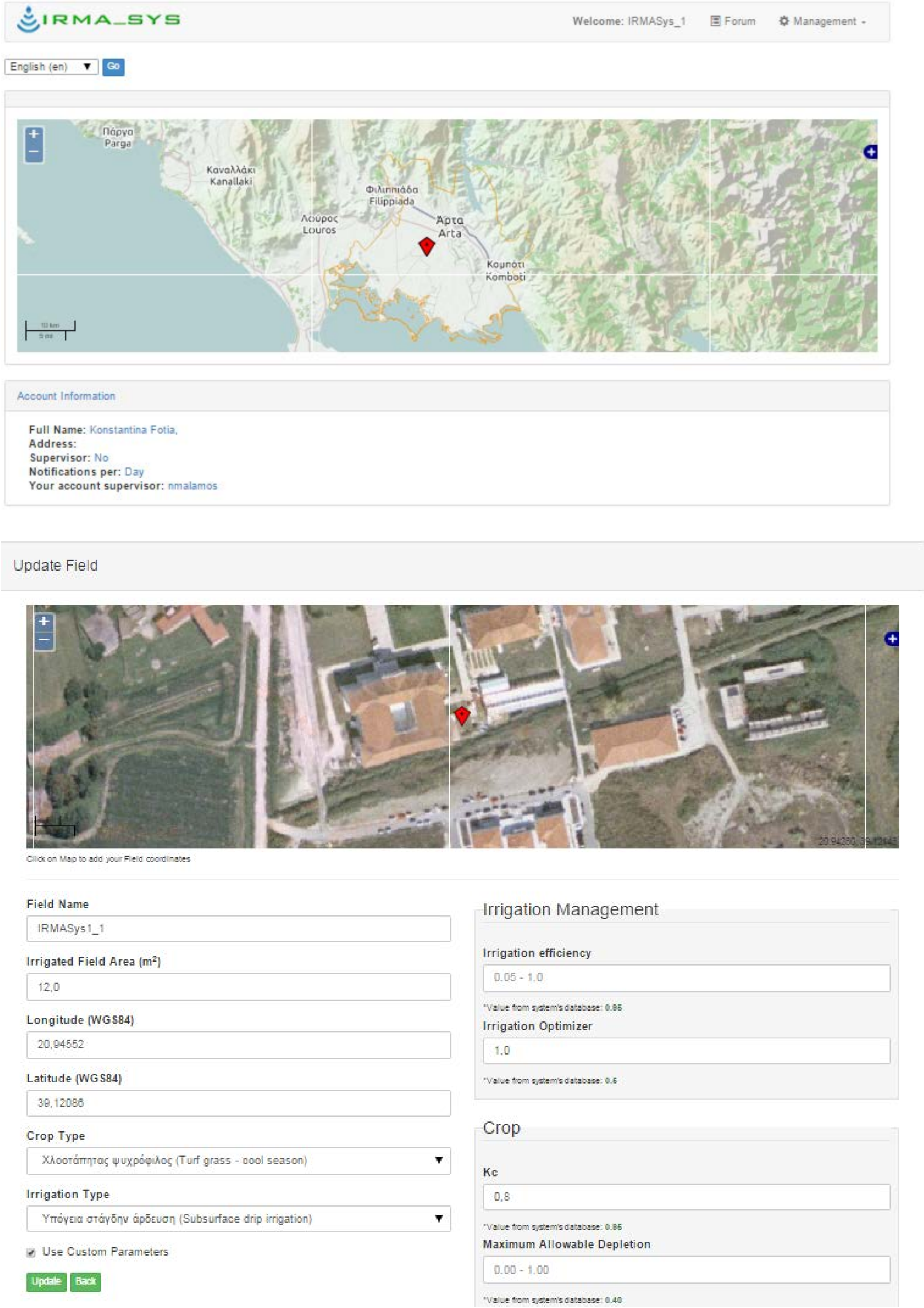


Fig. 28 3IS_UG field overview screen-shots

The email notifications regarding estimated field condition and the need for irrigation was selected to be sent every day (the message was sent at 5:00 in the morning).

Evaluation period and system data

The evaluation period spanned from July to September 2015. 78 irrigation events were applied from July 3rd to September 29th.

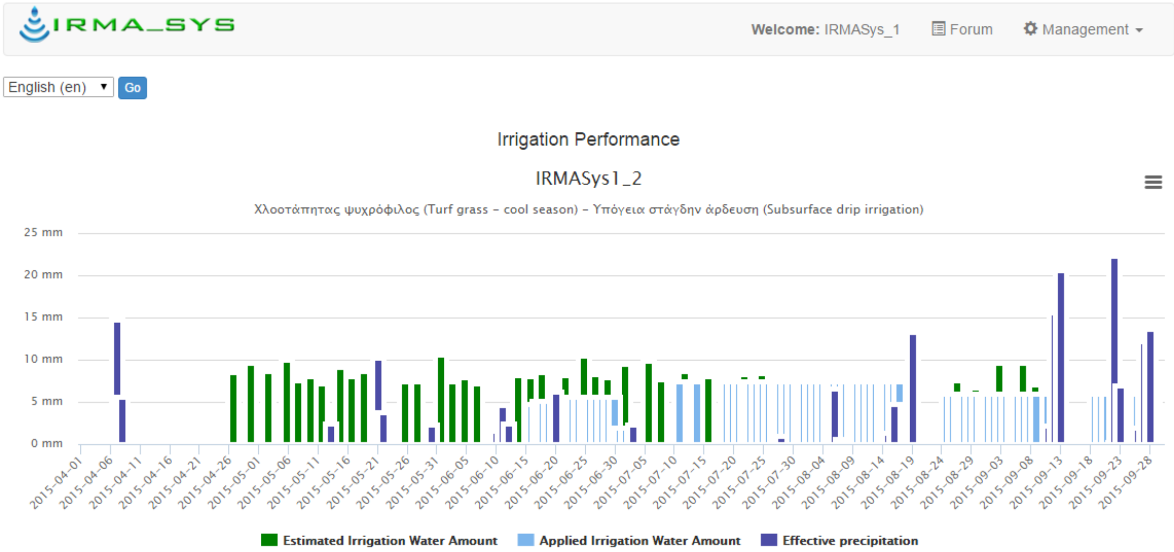


Fig. 29 Irrigation performance diagram as provided by the service for 1_2 treatment

According to IRMA_sys, the following facts were registered for the evaluation period:

- Total Effective Precipitation: 179.7 mm
- Total Estimated Irrigation Water Amount: 331.3 mm
- Total Applied Irrigation Water Amount: 483.8 mm
- Percentage difference: +46.0 %

The notifications reports provided by the system during the evaluation period are listed in Table 8

Table 8 Notification reports for 3IS_UG (original every day recommendations were converted using a 2 days basis)

Date of notification report	for the period	Recommended volume (mm)	Rec. volume (m^3)	to be applied on
3/7/2015	03/07/2015 - 05/07/2015	does not need to be irrigated		
5/7/2015	05/07/2015 - 07/07/2015	does not need to be irrigated		
7/7/2015	07/07/2015 - 09/07/2015	does not need to be irrigated		
9/7/2015	09/07/2015 - 11/07/2015	10.70	0.13	09/7/2015 08:00:00
11/7/2015	11/07/2015 - 13/07/2015	16.36	0.20	11/7/2015 00:00:00
11/7/2015	11/07/2015 - 13/07/2015	10.63	0.13	11/7/2015 14:00:00
13/7/2015	13/07/2015 - 15/07/2015	11.87	0.14	13/7/2015 00:00:00

Date of notification report	for the period	Recommended volume (mm)	Rec. volume (m^3)	to be applied on
13/7/2015	13/07/2015 - 15/07/2015	10.18	0.12	14/7/2015 12:00:00
15/7/2015	15/07/2015 - 17/07/2015	does not need to be irrigated		
17/7/2015	17/07/2015 - 19/07/2015	does not need to be irrigated		
19/7/2015	19/07/2015 - 21/07/2015	does not need to be irrigated		
21/7/2015	21/07/2015 - 23/07/2015	6.93	0.08	21/7/2015 15:00:00
21/7/2015	21/07/2015 - 23/07/2015	7.43	0.09	22/07/2015 14:00:00
23/7/2015	23/07/2015 - 25/07/2015	7.30	0.09	23/07/2015 13:00:00
23/7/2015	23/07/2015 - 25/07/2016	6.81	0.08	24/7/2015 14:00:00
25/7/2015	25/07/2015 - 27/07/2015	9.96	0.12	25/7/2015 00:00:00
25/7/2015	25/07/2015 - 27/07/2016	7.31	0.09	26/7/2015 14:00:00
27/7/2015	27/07/2015 - 29/07/2015	12.65	0.15	27/07/2015 00:00:00
27/7/2015	27/07/2015 - 29/07/2016	6.78	0.08	28/07/2015 12:00:00
29/7/2015	29/07/2015 - 31/07/2015	6.86	0.08	29/7/2015 13:00:00
29/7/2015	29/07/2015 - 31/07/2016	6.84	0.08	30/7/2015 16:00:00
31/7/2015	31/07/2015 - 02/08/2015	7.99	0.10	31/7/2015 00:00:00
31/7/2015	31/07/2015 - 02/08/2016	6.95	0.08	01/08/2015 10:00:00
2/8/2015	02/08/2015 - 04/08/2015	6.88	0.08	02/08/2015 10:00:00
2/8/2015	02/08/2015 - 04/08/2015	7.24	0.09	03/08/2015 14:00:00
4/8/2015	04/08/2015 - 06/08/2015	10.07	0.12	04/08/2015 00:00:00
4/8/2015	04/08/2015 - 06/08/2015	7.05	0.08	05/08/2015 10:00:00
6/8/2015	06/08/2015 - 08/08/2015	7.13	0.09	07/08/2015 15:00:00
8/8/2015	08/08/2015 - 10/08/2015	7.26	0.09	08/08/2015 13:00:00
8/8/2015	08/08/2015 - 10/08/2015	6.79	0.08	09/08/2015 14:00:00
10/8/2015	10/08/2015 - 12/08/2015	9.22	0.11	10/08/2015 01:00:00
10/8/2015	10/08/2015 - 12/08/2016	7.33	0.09	11/08/2015 14:00:00
12/8/2015	12/08/2015 - 14/08/2015	12.03	0.14	12/08/2015 01:00:00
12/8/2015	12/08/2015 - 14/08/2015	6.99	0.08	13/08/2015 15:00:00
14/8/2015	14/08/2015 - 16/08/2015	11.99	0.14	14/08/2015 01:00:00
14/8/2015	14/08/2015 - 16/08/2015	7.09	0.09	15/08/2015 13:00:00
16/8/2015	16/08/2015 - 18/08/2015	9.82	0.12	16/08/2015 01:00:01
16/8/2015	16/08/2015 - 18/08/2016	7.09	0.09	17/08/2015 17:00:01
18/8/2015	18/08/2015 - 20/08/2015	does not need to be irrigated		
20/8/2015	20/08/2015 - 22/08/2015	does not need to be irrigated		
22/8/2015	22/08/2015 - 24/08/2015	does not need to be irrigated		
24/8/2015	24/08/2015 - 26/08/2015	7.17	0.09	25/08/2015 12:00:00
26/8/2015	26/08/2015 - 28/08/2015	7.20	0.09	26/08/2015 11:00:01
26/8/2015	26/08/2015 - 28/08/2016	6.79	0.08	27/08/2015 14:00:01
28/8/2015	27/08/2015 - 29/08/2015	6.92	0.08	28/08/2015 12:00:00
30/8/2015	30/08/2015 - 01/09/2015	9.46	0.11	30/08/2015 01:00:01
30/8/2015	30/08/2015 - 01/09/2016	6.91	0.08	31/08/2015 10:00:01

Date of notification report	for the period	Recommended volume (mm)	Rec. volume (m^3)	to be applied on
1/9/2015	01/09/2015 - 03/09/2015	7.44	0.09	01/09/2015 01:00:01
1/9/2015	01/09/2015 - 03/09/2015	6.82	0.08	02/09/2015 14:00:01
3/9/2015	03/09/2015 - 05/09/2015	7.75	0.09	03/09/2015 01:00:01
3/9/2015	03/09/2015 - 05/09/2016	7.06	0.08	04/09/2015 16:00:00
5/9/2015	05/09/2015 - 07/09/2015	6.75	0.08	05/09/2015 10:00:01
7/9/2015	07/09/2015 - 09/09/2015	12.64	0.15	07/09/2015 01:00:00
7/9/2015	07/09/2015 - 09/09/2015	6.87	0.08	08/09/2015 16:00:01
9/9/2015	09/09/2015 - 11/09/2015	11.43	0.14	09/09/2015 01:00:01
11/9/2015	11/09/2015 - 13/09/2015	does not need to be irrigated		
13/9/2015	13/09/2015 - 15/09/2015	does not need to be irrigated		
15/9/2015	15/09/2015 - 17/09/2015	does not need to be irrigated		
17/9/2015	17/09/2015 - 19/09/2015	does not need to be irrigated		
19/9/2015	19/09/2015 - 21/09/2015	does not need to be irrigated		
21/9/2015	21/09/2015 - 23/09/2015	does not need to be irrigated		
23/9/2015	23/09/2015 - 25/09/2015	does not need to be irrigated		
25/9/2015	25/09/2015 - 27/09/2015	does not need to be irrigated		
27/9/2015	27/09/2015 - 29/09/2015	does not need to be irrigated		
29/9/2015	29/09/2015 - 01/10/2015	does not need to be irrigated		

Fig. 30 provides an image regarding the operation values of the system from July 3rd up to the end of September 2015.

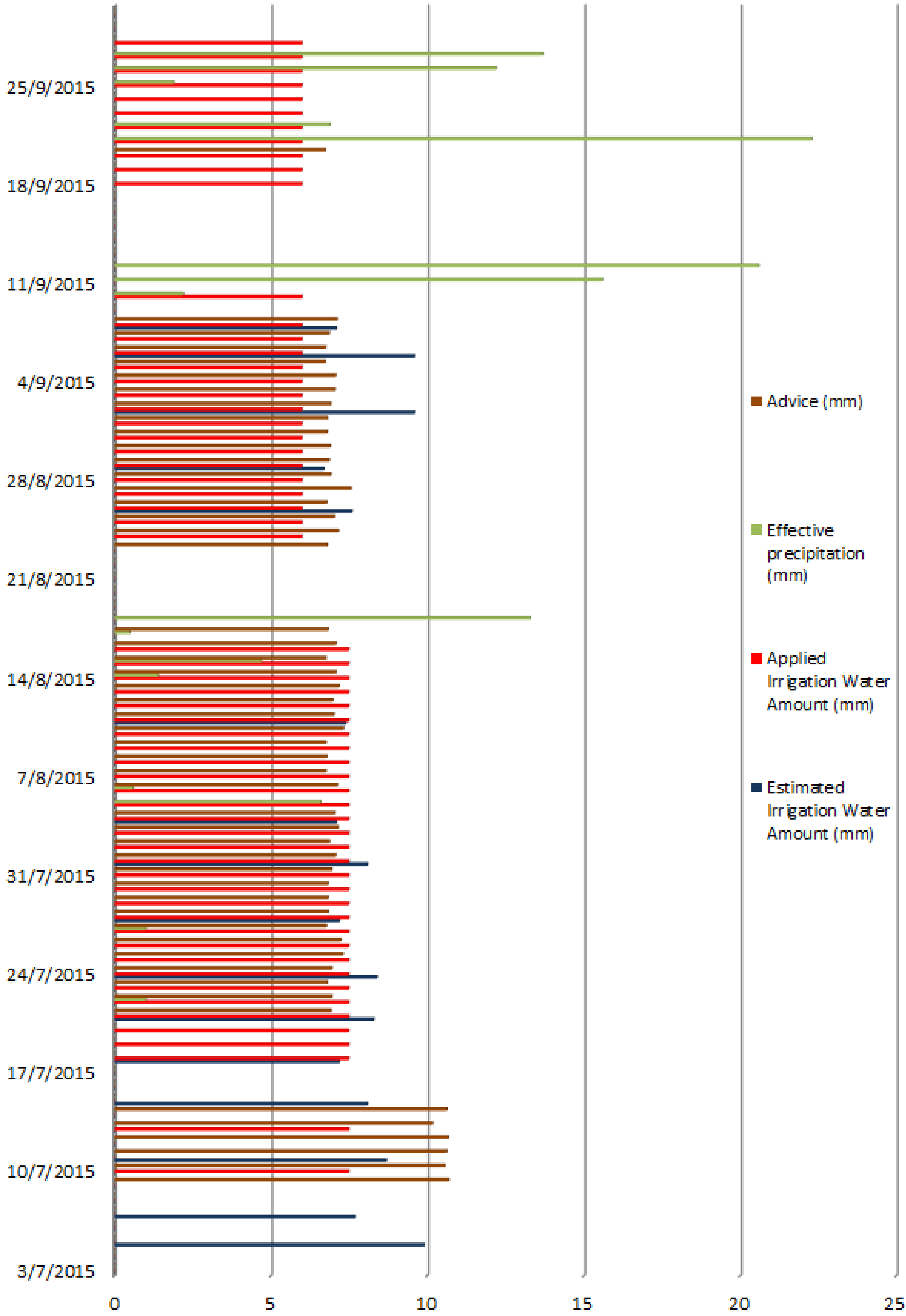


Fig. 30 System data for 3IS_UG IRMA_sys (1_2) treatment during the evaluation period

Soil moisture comparison

Soil moisture of the control treatments as shown in Fig. 31 fluctuated during the evaluation period mostly above the FC threshold, while soil moisture recorded in the IRMASys1_2 treatment plots was generally below FC.

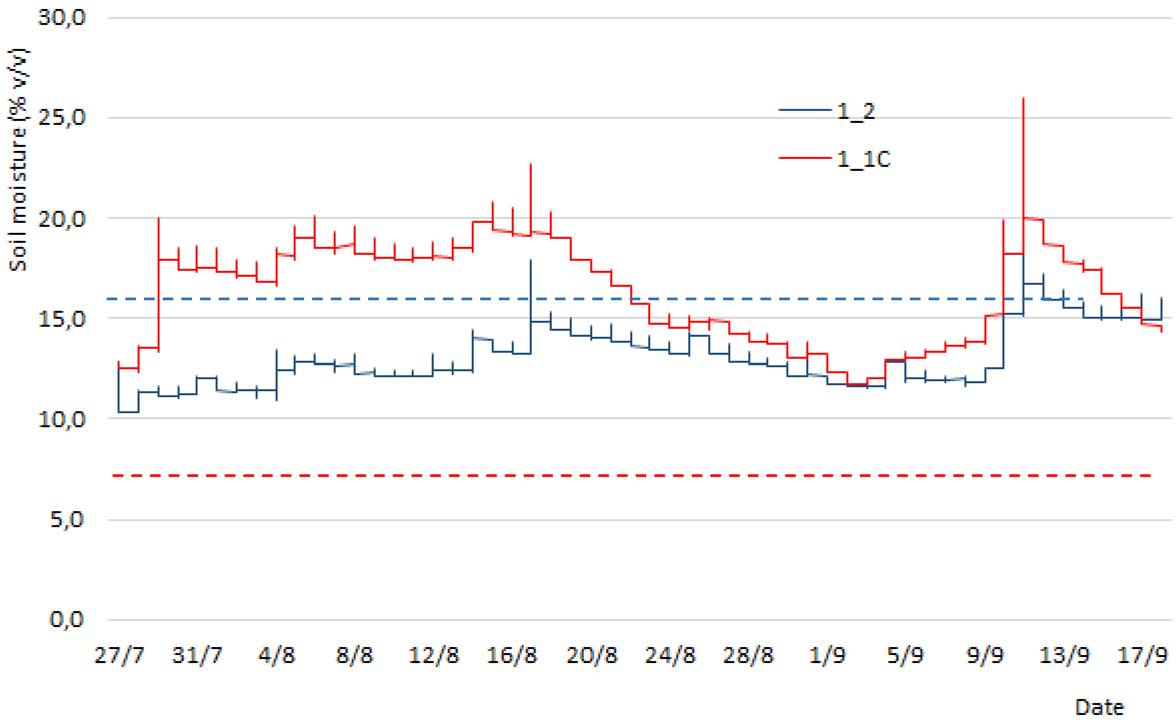


Fig. 31 Soil moisture for the two treatments, 1_C and 1_2 (blue line, --- FC level; red horizontal line, --- PWP level)

Irrigation water consumption comparison

Fig. 32 shows the cumulative water consumption for the two treatments. A third parameter, the theoretically expected irrigation needs (estimated as the landscape evapotranspiration for 2015 divided by the application efficiency minus the effective rainfall for 2015) is also presented in the same diagram.

During the evaluation period the 1_2 treatment consumed 41.46 % less water than the reference treatment.

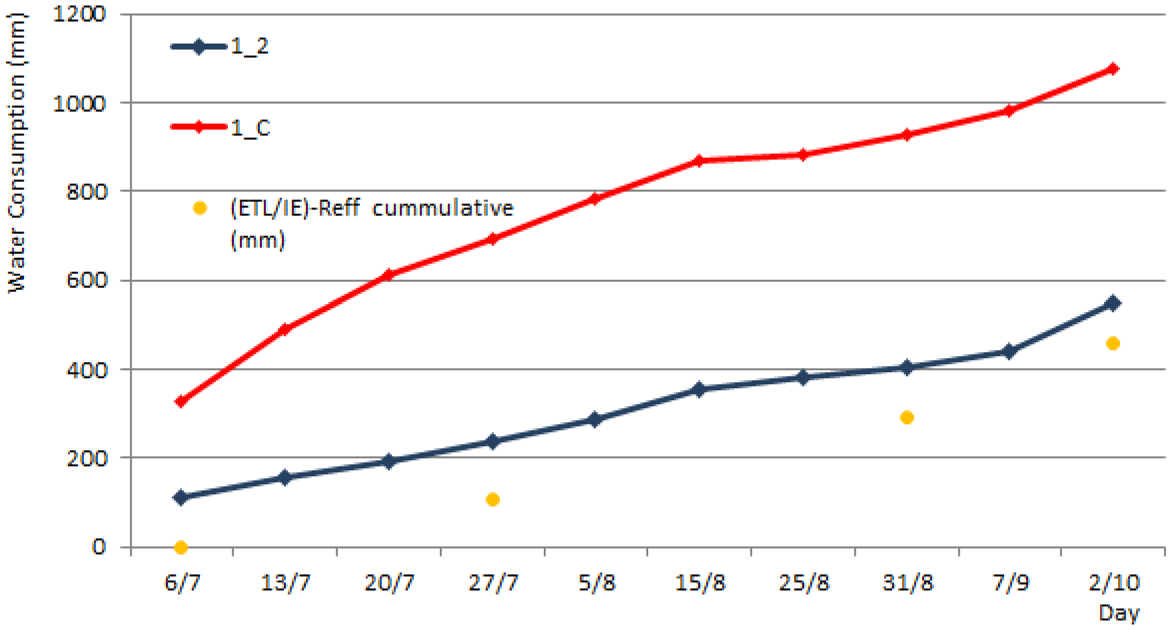


Fig. 32 Water consumption for the two treatments (1_C and 1_2)

Turfgrass growth comparison

Concerning turfgrass growth, Student's t-test revealed no statistically significant difference in the aerial part evolution between treatments as it is depicted in Fig. 33.

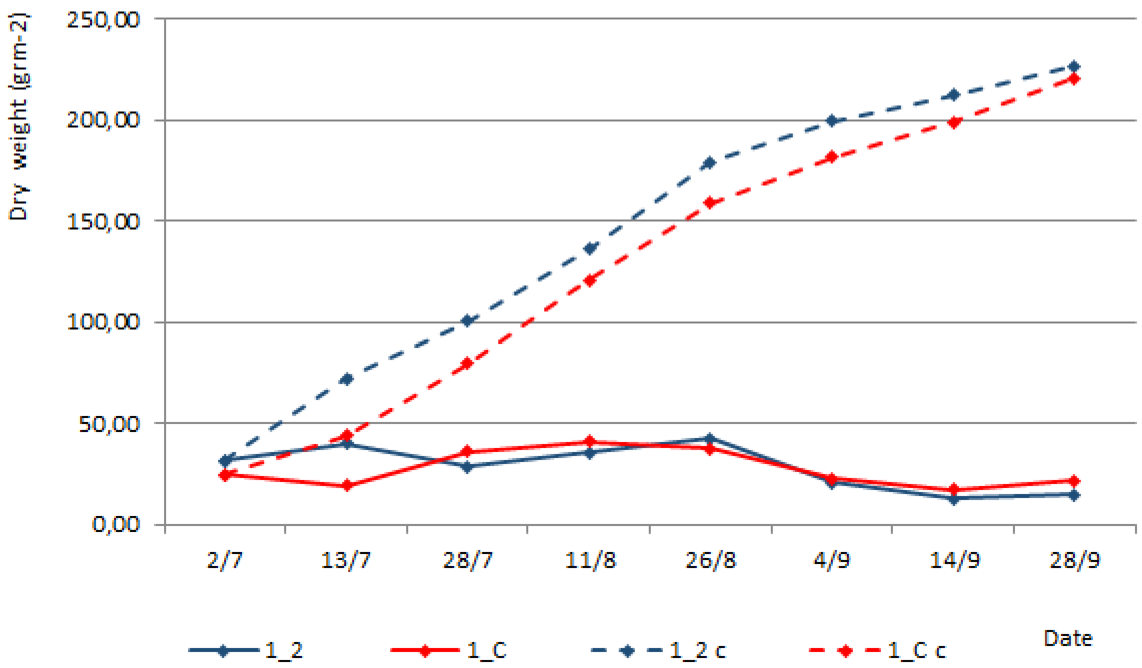


Fig. 33 Evolution of the aerial part growth for 1_1C and 1_1 treatments

Turfgrass quality comparison

Both turfgrass quality indices (PRI, NDVI) revealed no statistically significant difference between the two treatments as determined by Student's t-test (CL 95%).

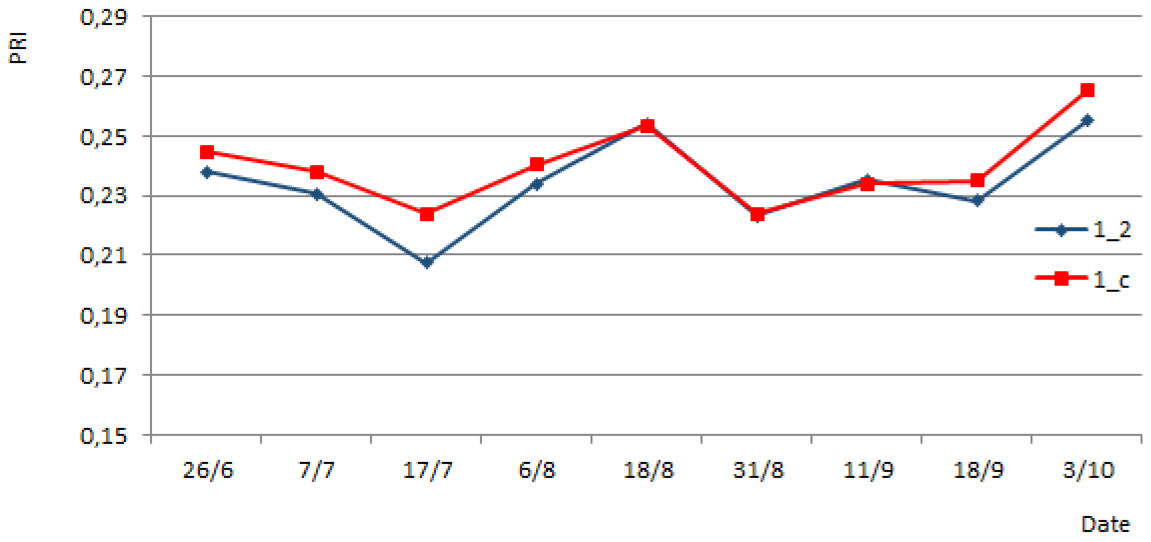


Fig. 34 PRI index evolution for 1_C and 1_2 treatments (PRIcropscan = (R560 - R510) / (R560+ R510))

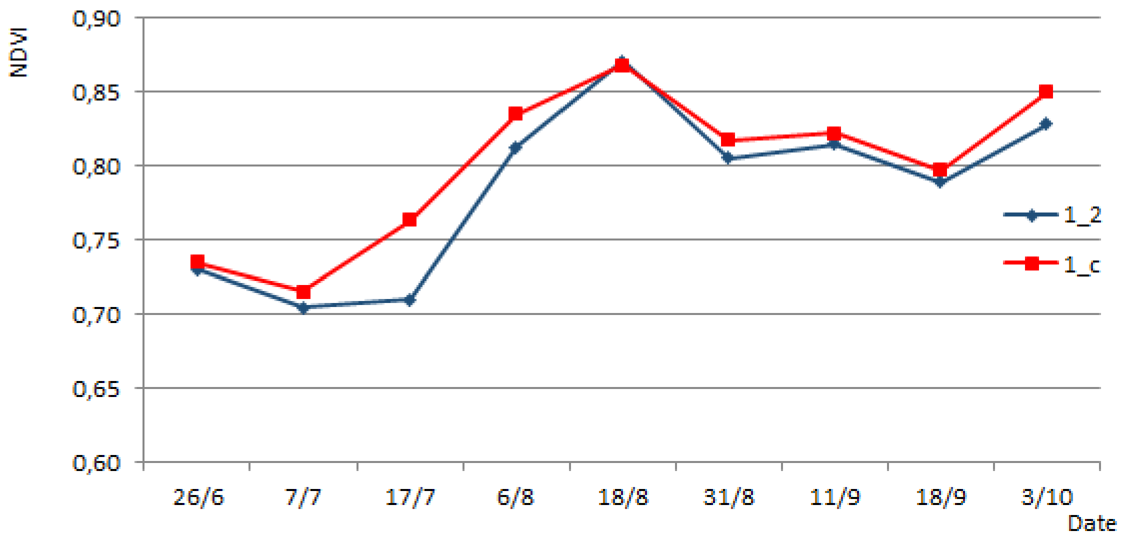


Fig. 35 NDVI for 1_C and 1_2 treatments (NDVIcropscan = (R810 - R660) / (R810+ R660))

Case study outcomes

Application of IRMA_sys irrigation model resulted in 41.46% less water consumption without effecting plant's performance in quantitative and qualitative means. The great consumption of water a the reference treatment could be attributed to problems in the theoretical setup of the irrigation schedule.

Soil moisture following the IRMA_sys tool recommendations was maintained within the limits of the available water zone although it was in lower levels compared to reference treatment. Dry mass measurements demonstrated no effect of different treatments in turfgrass growth patterns. Additionally concerning the appearance of turfgrass subjected to the different treatments there was no difference observed implying that such a decision support tool can ensure cost effective water management.

CASE STUDY 3: Kiwi-fruit orchard

This case study concerned a kiwi-fruit orchard. The irrigation events that the farmer applied and the relevant water volume were registered and then compared to the recommendations of IRMA_sys for this specific filed during the relevant period.

Field characteristics

The field is located near the village of Kolomodia, at the plain of Arta (Fig. 36). Its total area is 0.9 ha while the cultivated area is 0.86 ha. Kiwi plants are planted following a 4.5x4.5 m grid and supported using a pergola system (Fig. 37).

The field is divided in two irrigation stations (A and B; Fig. 38). Station A hosts 10 irrigation lines while Station B hosts 9 lines. Each line serves 19-21 outlets (following the relevant number of plants). Each line is divided in 2 branches of almost equal length (one from the connection towards north-east and one towards south-west). Irrigation is performed using 120 lph micro-sprinklers (1 per plant).

Soil analysis was performed in the framework of an irrigation audit. During the same audit water application uniformity was also calculated (Christiansen uniformity – CU was found to be 60%).

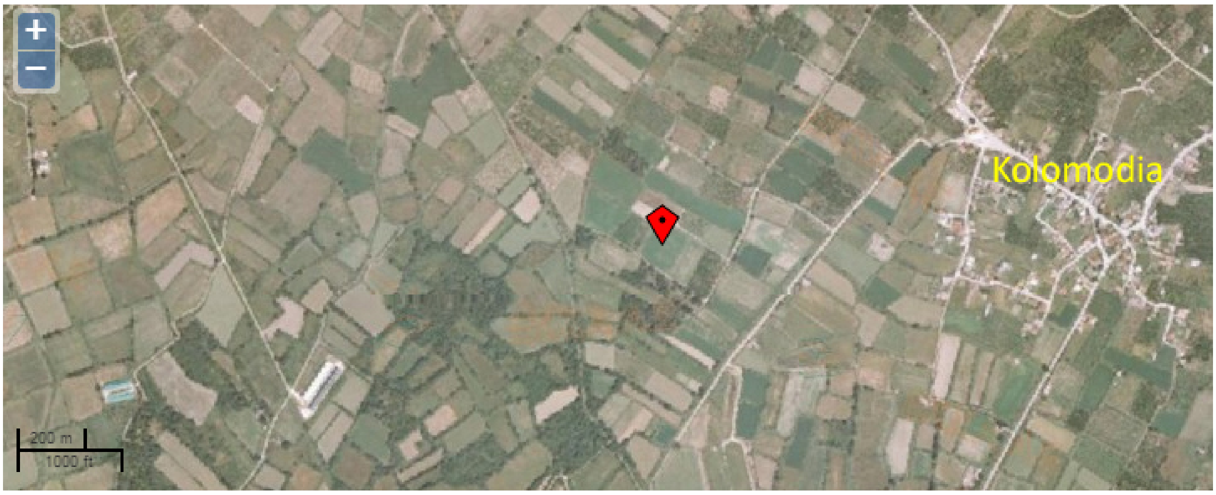


Fig. 36 Location of case study 2 field (kiwi orchard)

Fig. 37 General view of case study 2 field (kiwi orchard) from the south west border of the field

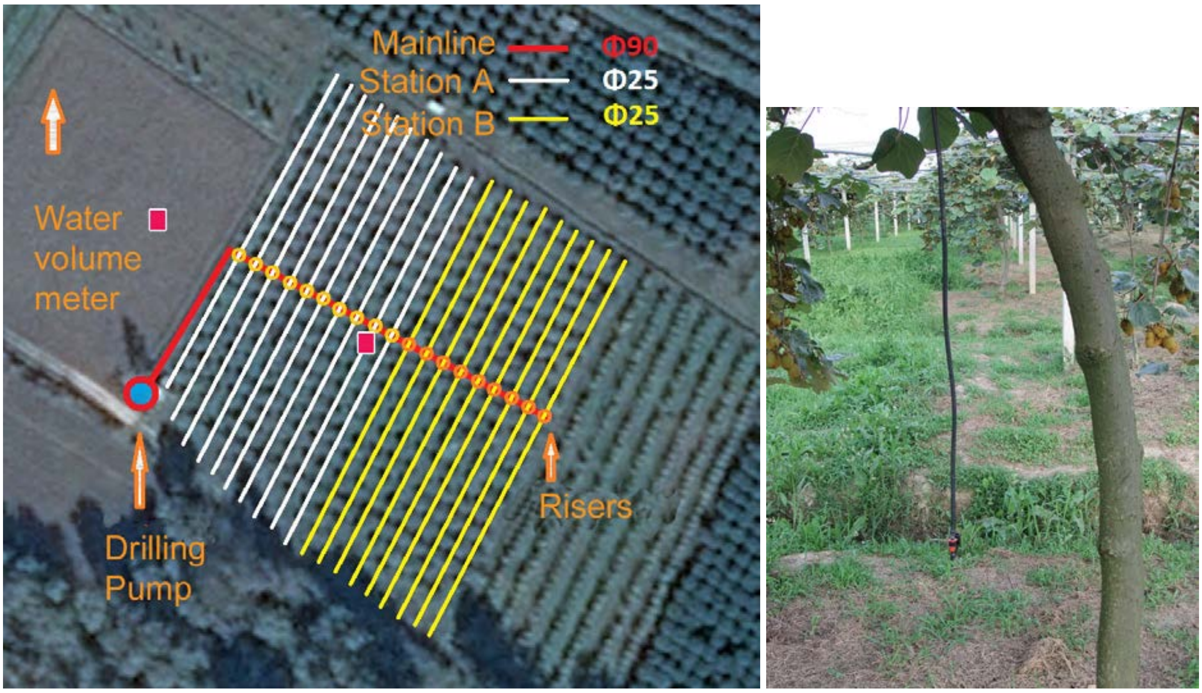


Fig. 38 The irrigation system of the kiwi orchard and the 120lph micro-sprinkler

Table 9 and Table 10 summarise the field characteristics and the parameters that were used regarding the crop, the soil and the irrigation system as they were inserted in the IRMA_sys.

Table 9 Kiwi orchard characteristics in IRMA_sys

Field name	Kiwi orchard Michalis
Irrigated Field Area (m^2)	4,300 (because only Station A, half of the field was considered in the calculations)
Longitude (WGS84)	20.96942
Latitude (WGS84)	39.09694
Crop Type	Kiwi
Irrigation Type	Micro sprinklers

Table 10 Kiwi orchard parameters as inserted in IRMA_sys

Parameter category	Parameter	Default system value (value from the system's database)	Custom parameter
System	Irrigation efficiency	0.80	Default value was used
	Irrigation optimizer	0.50	0.20
Plant	Kc	0.80	1.05
	Maximum Allowable Depletion	0.35	Default value was used
	Estimated root depth (max)	1.30	Default value was used
	Estimated root depth (min)	0.70	Default value was used
Soil	Field Capacity	0.39	0.15
	Permanent Wilting Point	0.10	0.06
	Soil moisture at saturation	0.50	0.35

Evaluation period and system data

The evaluation period started from July 22 and lasted up to September 15. The measurement of the water consumption during the evaluation period was made by one 1'' volumetric dry dial water meter (1L resolution) that measured the volume of water of one branch of station A. Measurements were registered manually after the completion of each irrigation event.

Fig. 39 presents the IRMA_sys data and recommendations diagram for the kiwi orchard under consideration.

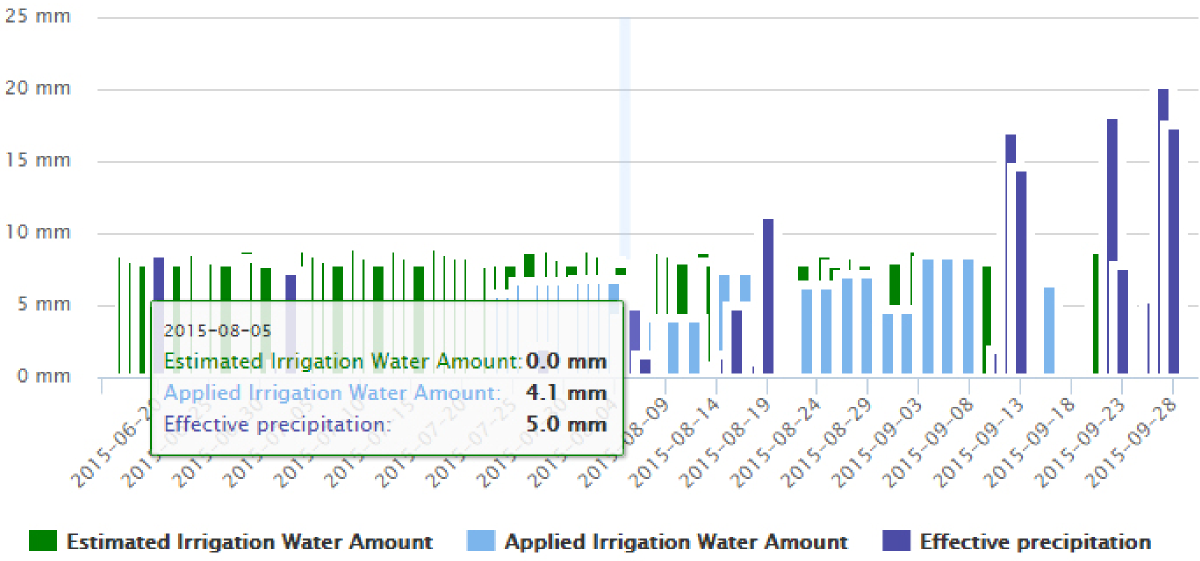


Fig. 39 Irrigation performance diagram as provided by the service for case study 3 (kiwi orchard)

Irrigation water consumption comparison

The calculations from the water meter data (difference of two subsequent measurements multiplied by 20 (the number of branches of station A) provided an estimation regarding the total volume for the station for each irrigation event, the division of this number by the station area provided the corresponding mm value) showed the outlets provided an average flow of 56.13 (± 2.43 SE[2]) lpm which is far away from their nominal 120lph flow value.

According to IRMA_sys, the Estimated Irrigation Water Amount for the almost 2 month evaluation period was 259.70 mm (the relevant Effective precipitation for the field location was estimated by the system to be 62.50mm). The farmer applied 200.14 mm of water (Fig. 40), which is about 23% less.

If the expected discharge of the micro-sprinklers (120lph) was taken into account the total duration of the irrigation events that the farmer applied (34 events which lasted 2.3h each – average value, ±0.4 SE), then we could assume that the farmer thought of delivering about 461 mm to Station A, which counts for 78% more water.

[2]SE: Standard error value

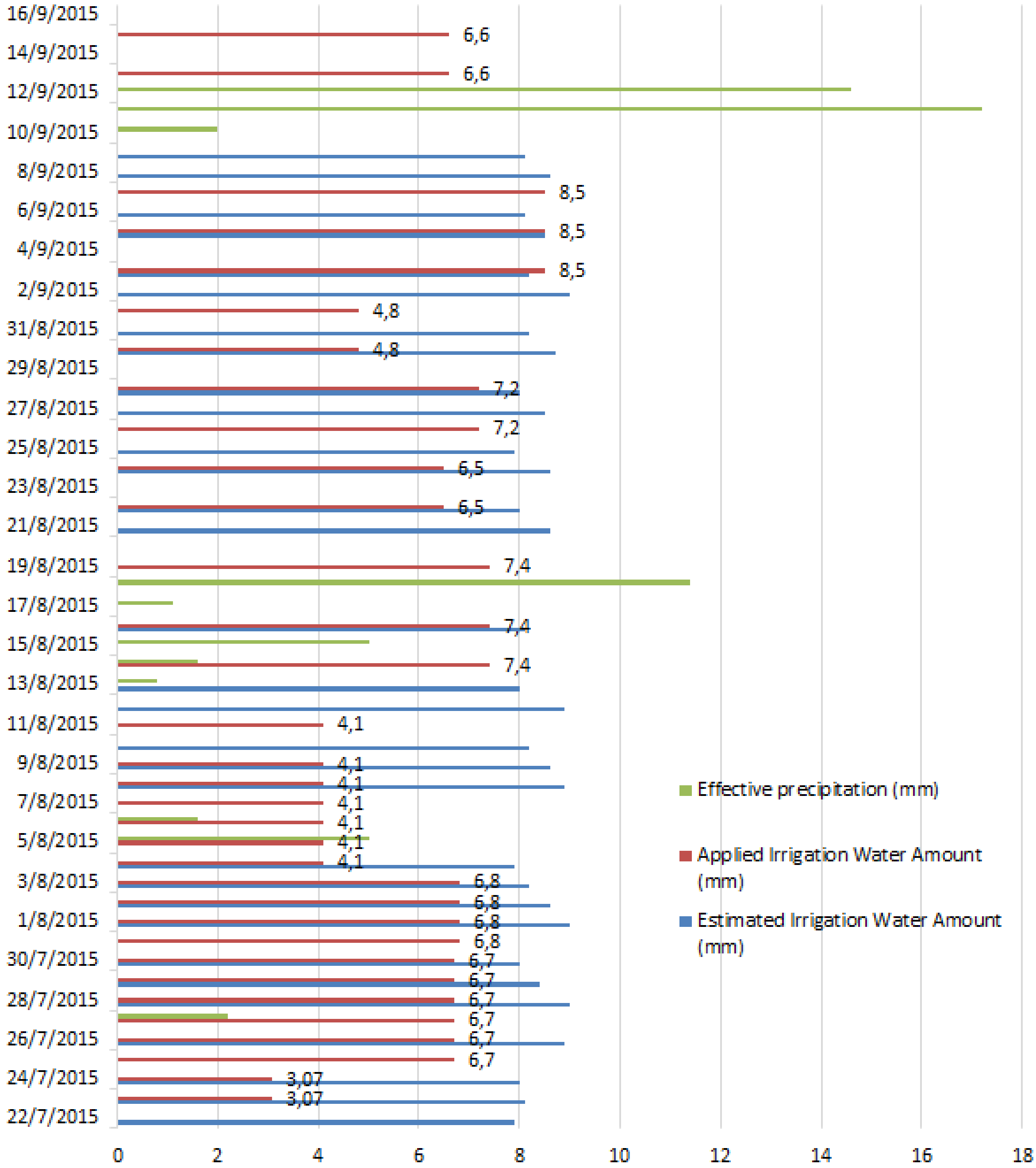


Fig. 40 System data and applied irrigation water volume for case study 3 (kiwi orchard)

A typical experimental setup is needed in order to asses different set of parameters of the system and to evaluate the effects of deficit irrigation to the economic output of the cultivation.

CASE STUDY 4: Tangerine orchard

This case study concerned a tangerine orchard. The irrigation events that the farmer applied and the relevant water volume were registered and then compared to the recommendations of IRMA_sys for this specific filed during the relevant period.

Field characteristics

The field is located between the villages of Chanopoulo and Rocka, at the plain of Arta (Fig. 41). Its total area is 0.49 ha. Tangerine plants are planted following a 5x5 m grid.

Irrigation is applied using a high pressure micro – sprinkler system which is used also for anti-frost protection (this dual purpose system is a wrong yet very extensively applied solution for the plain of Arta). 1 90lpm (1m radius) micro – sprinkler is placed next to each plant (170 in total). Typically 2 irrigations are performed each year. The irrigation period is from July to the middle of September and each irrigation event typically lasts for 10h.

Soil analysis was performed in the framework of an irrigation audit. It has to be noted that the user did not inserted in the system the soil parameters that were indicated by the analysis but used the default system values for the field location (as indicated by the soil map of the area that is contained in the system).

During the same audit water application uniformity was also calculated (Christiansen uniformity – CU was found to be 75%)

Fig. 41 Location of case study 4 field (tangerine orchard)

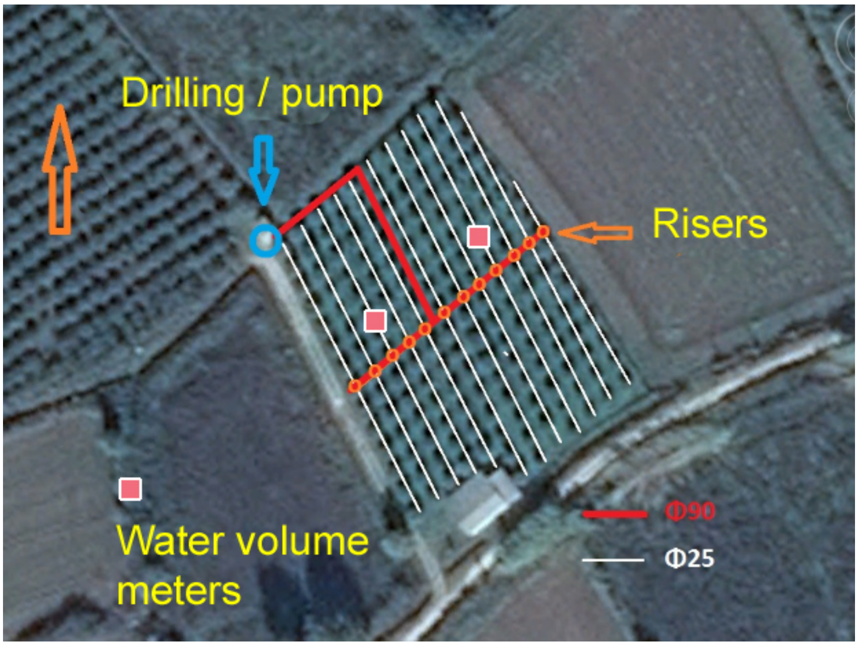


Fig. 42 Irrigation system layout and water meters location for case study 4 field (tangerine orchard)

Fig. 43 On site measurements of water consumption at case 4 field (tangerine orchard)

Table 11 and Table 12 summarise the field characteristics and the parameters that were used regarding the crop, the soil and the irrigation system as they were inserted in the IRMA_sys.

Table 11 Tangerine orchard characteristics in IRMA_sys

Field name	Tangerine orchard PT
Irrigated Field Area (m^2)	4,900
Longitude (WGS84)	20.92618
Latitude (WGS84)	39.18112
Crop Type	Citrus – 70% canopy
Irrigation Type	Micro sprinklers

Table 12 Tangerine orchard parameters as inserted in IRMA_sys

Parameter category	Parameter	Default system value (value from the system's database)	Custom parameter
System	Irrigation efficiency	0.80	Default value was used
	Irrigation optimizer	0.50	0.30
Plant	Kc	0.55	0.65
	Maximum Allowable Depletion	0.35	Default value was used
	Estimated root depth (max)	1.5	Default value was used
	Estimated root depth (min)	1.20	Default value was used
Soil	Field Capacity	0.29	Default value was used
	Permanent Wilting Point	0.14	Default value was used
	Soil moisture at saturation	0.43	Default value was used

Evaluation period and system data

The evaluation period started from July 20 and lasted up to September 15. The measurement of the water consumption during the evaluation period was made by two 1'' volumetric dry dial water meters (1L resolution). Measurements were registered manually after the completion of each irrigation event.

Irrigation water consumption comparison

The farmer applied 4 irrigations during the evaluation period, which lasted: 6 h on 20/7/2015; 4 h on 10/8/2015; 6 h on 24/8/2015 and 6 h on 6/9/2015.

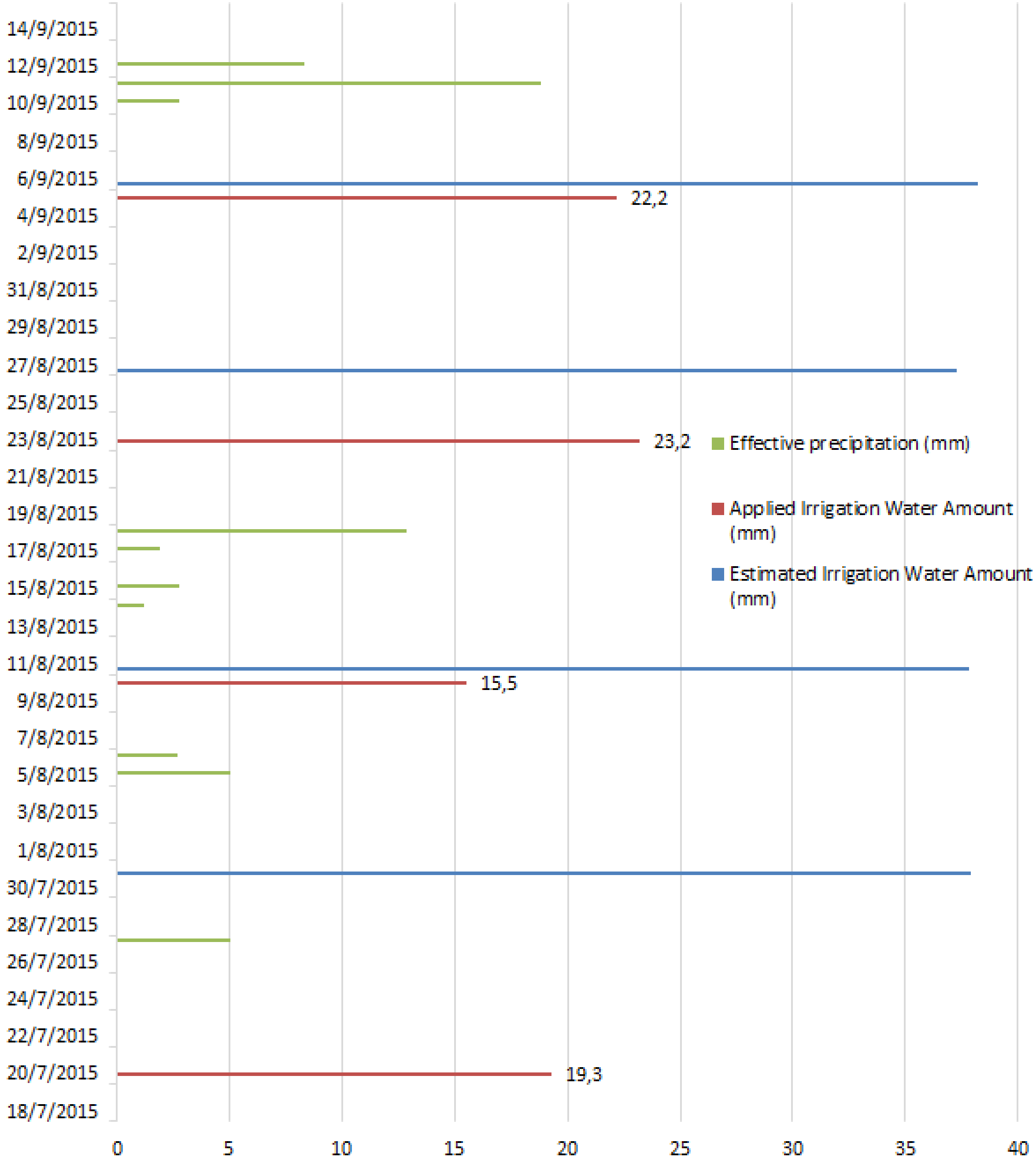


Fig. 44 System data and applied irrigation water volume for case study 4 (tangerine orchard)

The calculations from the water meter data (difference of two subsequent measurements multiplied by 22 (the number of branches) provided an estimation regarding the total volume for the station for each irrigation event, the division of this number by the station area provided the corresponding mm value) showed the outlets provided an average flow of 105.58 (± 4.50[3]) lpm which is a bit away from their nominal 90 lph flow value.

[3] Standard error value

According to IRMA_sys, the Estimated Irrigation Water Amount for the almost 2 month evaluation period was 151.20 mm (the relevant Effective precipitation for the field location was estimated by the system to be 61.40mm). The farmer applied 80.20 mm of water (Fig. 44), which is about 47% less. A typical experimental setup is needed in order to asses different set of parameters of the system and to evaluate the effects of deficit irrigation to the economic output of the cultivation.

Meteorological network operation and data time-series

Meteorological stations problems, troubleshooting and gained experience

All the meteorological stations of the system have been installed but the operation for stations of level B and C that are dependent by the operation of a PC from which the data are retrieved, proved to be problematic. Thus the system is using only the most reliable of the data, those that are provided by the level A, agrometeorological stations.

From 1/7 up to 31/8 the pyranometer of the level A station at TEIEP was off due to a technical problem. The supplier provided the spare part after some time as it had to be removed from the mast, send to the company, checked by the technicians and then wait for a new one to be imported to Greece and send to TEIEP.

The good news were that the system could function as it is based on spatial regression procedures regarding the calculation of meteorological parameters for each field, thus the loss of data from a sensor, affects the accuracy but does not make impossible its operation.

SIM MB usage information

One of the level A stations, sends the data through a SIM card connection. Table 13 presents a typical SIM MB usage for one month period.

Table 13 SIM MB usage

Period		Number of calls	Calls duration, total (hh:mm:ss)	Data volume, total (MB)
From	To			
27/5/2015	26/6/2015	1127	623:23:49	11,3

Evaluation of weather forecast data for the plain of Arta

In the framework of the evaluation of the system, the degree of success of weather forecasts for the plain of Arta was also assessed. The assessment was made by the National Observatory of Athens that provides the relevant information to IRMA_sys.

Description of BOLAM model setup

In the frame of the project the most recent version of BOLAM model, which is based on previous versions of the model described by Buzzi et al. (1994; 1997; 1998) and Buzzi and Foschini (2000). The main features of the model are summarized below:

- hydrostatic primitive equations;
- dependent variables: surface pressure, u, v, potential temperature, specific humidity, and five microphysical variables;
- Arakawa C grid (rotated lat.-lon. coordinates); σ vertical coordinate;
- forward-backward (FB) 3-D Eulerian advection scheme (Malguzzi and Tartaglione, 1999) and semi-Lagrangian advection of hydrometeors;
- split-explicit time scheme (FB for gravity modes);
- 4th order horizontal diffusion and 2nd order divergence diffusion;
- Davies-Källberg-Lehmann (Lehmann, 1992) relaxation scheme for lateral boundary conditions.

Physical parameterizations include:

- dry adiabatic adjustment;
- radiation: infrared and solar, interacting with clouds (Ritter and Geleyn, 1992);
- vertical diffusion (surface layer and planetary boundary layer parameterization) depending on Richardson number (Louis, 1979; Louis et al., 1982);
- surface thermal and water balance (3 soil layers);
- explicit microphysical scheme with two water and three ice species;
- convective parameterization scheme proposed by Kain and Fritsch (1990, 1993), with implementation (see Buzzi and Foschini, 2000) of the modifications suggested by Spencer and Stensrud (1998), as it concerns the delay of downdrafts in newly developed convection.

Specifically, model forecasts regard to precipitation; the microphysical scheme was coded mainly on the basis of the transformation process models described in Schultz (1995). This is a simple and computationally efficient approach to represent cloud processes in an operational model. The scheme includes five hydrometeor categories: cloud ice, cloud water, rain, snow, and graupel. In his paper, Schultz compares the results of his scheme against both the results of a well-documented research microphysics algorithm and observations. He found that both schemes provided similar and generally skilful precipitation forecasts, with the advantage that his scheme is about 7-10 times faster than the research oriented algorithm.

The sub-grid scale precipitation is treated in BOLAM following the Kain-Fritsch convective parameterization scheme (Kain and Fritsch, 1993). The Kain-Fritsch scheme is based on the Fritsch-Chappell scheme with improvements on the detrainment effect and the cloud model. It has been developed for mesoscale models with a grid size of a few tens of kilometers. In this scheme convection is triggered by lifting a lower-level slab layer with an impetus heating as a function of grid-scale vertical motion at the lifting condensation level. The Kain-Fritsch scheme, has shown considerable success in simulating the development and evolution of convection under a variety of convective and synoptic environments (Kuo et al., 1996; Wang and Seaman, 1997; Ferretti et al., 2000). Additionally, the Kain-Fritsch scheme has shown the most consistent behavior among a number of convective parameterization schemes implemented in MM5 model for the simulation of cold period precipitation cases over Greece (Kotroni and Lagouvardos, 2001).

BOLAM has the capability to perform one-way nested simulations, using two nested grid domains:

- the coarse grid consists of 135x110 points with a 0.21 deg horizontal grid interval (~23 km) centered at 41°N latitude and 15°E longitude, covering the area of the Eastern Mediterranean (Figure 1a). This configuration was valid for the second year of operational use, while during the first year the coarse grid covered about half of this domain (90x84 grid points).

- the fine grid consists of 160x148 points with 0.06 deg horizontal grid increment (~6 km) (~6.5 km), centered at 38°N latitude and 24°E longitude (approximately the position of Athens). The fine grid covers the Greek peninsula with its maritime areas expanding from the Ionian Sea in the west up to the Turkish coasts in the east (Fig. 45b).

For the project needs, the study area is enclosed with a red rectangle in Figure 1b. Data for this area are provided in the project's database with a time interval of 3 hours.

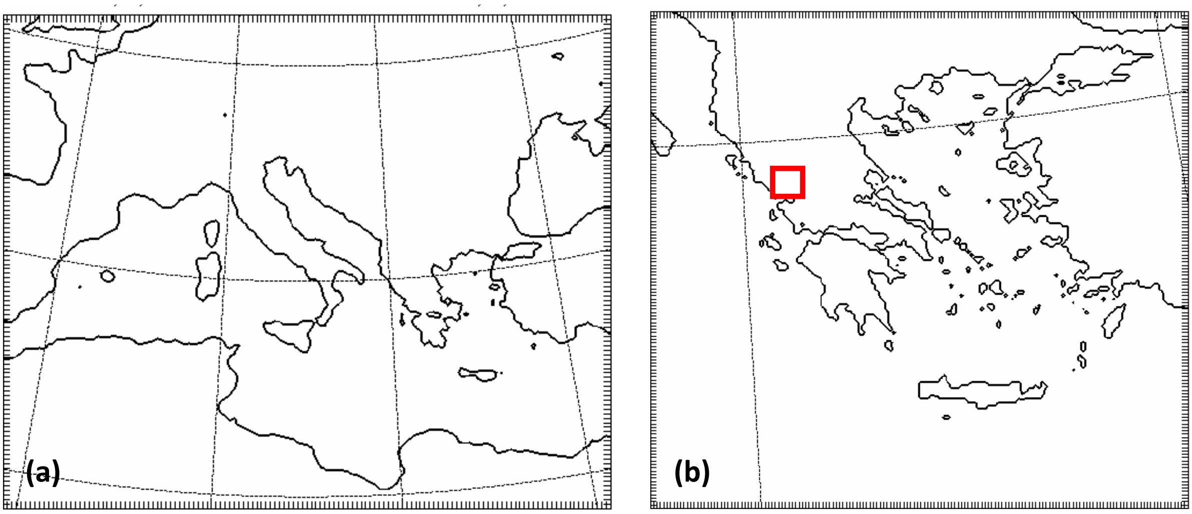


Fig. 45 Horizontal extension of (a) the coarse grid and (b) the fine grid of BOLAM model. The red square denotes the study area

In the vertical, 30 levels are used in the coarse grid and 36 levels in the fine grid, while model top has been set at about 10 hPa on both nests. The vertical resolution is higher in the boundary layer and, to a lesser extent, at the average tropopause level.

The Medium-Range Forecast (GFS, provided by the National Centers for Environmental Predictions-NCEP, USA) gridded analysis fields and 6 h interval forecasts, at 0.5 degree lat/lon horizontal grid increment, are used to initialize the model and to nudge the boundaries of the coarse grid during the simulation period. The orography fields are derived from a 30 arcsec resolution terrain data file provided by USGS.

Model verification

In order to evaluate the model skill in providing accurate precipitation forecasts during the studied period, a verification procedure has been undertaken for the studied area, against rain observations at Arta station. For the verification, the closest to Arta's station model grid point was selected. From the observed and forecast values a contingency table is built as shown in the following:

Table 14 Example of 2x2 contingency table

2x2 Contingency Table		**Event Observed**	
		Yes	No
Event Forecast	Yes	*A*	*B*
	No	*C*	*D*

where A is the number of events for which the model-forecast precipitation and the observed precipitation equaled or exceed a threshold (hits), B is the number of events for which only the model-forecast precipitation equaled or exceed a threshold (false alarm), C is the number of the events for which only the observed precipitation equaled or exceed a threshold (misses) and D is the number of the events for which neither the model-forecast precipitation nor the observed precipitation equaled or exceed a threshold (correct negatives). The following measures are calculated:

Bias, $\mathrm{B} = \dfrac{A+B}{A+C}$

Probability Of Detection, $POD = \dfrac{A}{A+C}$

False Alarm Ratio, $FAR = \dfrac{B}{A+B}$

Critical Success Index, $CSI = \dfrac{A}{A+B+C}$

In the framework of this study, the aforementioned statistical scores are calculated for 24-h observed rain exceeding 1 mm. The verification is made for the period from 1 September 2014 up to 30 April 2015 (8 months).

The bias measures the ratio of the frequency of forecast events to the frequency of observed events and indicates whether the model has a tendency to under predict (B<1) or over predict (B>1) events. Table 15 shows the bias score. The bias is very close to 1 (1.06) indicating no overestimation or underestimation of rain events.

Table 15 Results for the calculated statistical scores for 24-h accumulated rainfall exceeding 1 mm.

24-h rain exceeding 1 mm	
Bias	1.06
POD	0.77
FAR	0.27
CSI	0.60

As far as the ability of the model to correctly forecast the observed precipitation events is concerned, probability of detection (POD) has been calculated and it is also shown in Table 15. POD shows a value of 0.77 for 24-h accumulated rain exceeding 1 mm. Concerning the false alarm ratio (FAR) shown in the same table, it is 0.27, indicating that the model has low tendency to provide false alarms. Finally, the critical success index (CSI) is examined, a score that measures the fraction of observed and/or forecast events that were correctly predicted. CSI can be thought of as the accuracy when correct negatives have been removed from consideration and is sensitive to hits, penalizes both misses and false alarms and the unity is the perfect score, while 0 is the lowest possible value. The CSI score shown in Table 5 is very close to 0.6.

Finally, Fig. 46 shows the time evolution of 24-h rainfall (observed values in blue line and forecast values in red line), permitting to follow the day-by-day evolution of forecast values against observations, for the totality of the 242 days of the 8-month verification period.

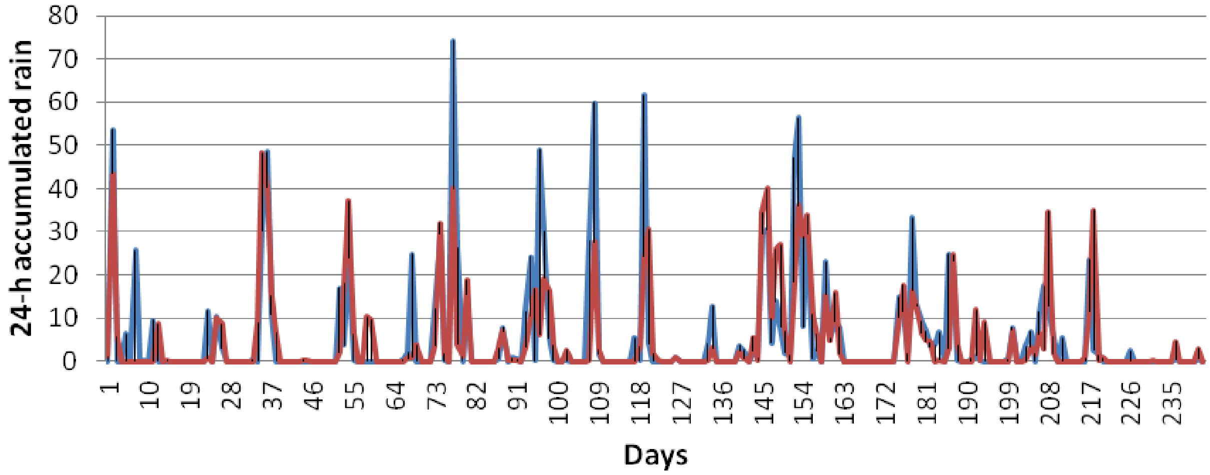


Fig. 46 Time evolution of 24-h rainfall (osberved values in blue line and forecast values in red line) for the totality of the 242 days of the 8-month verification period.

Spatial regression

For the needs of this WP, an exchange of ideas was performed on the methods of spatial regression of station data, such as kriging, or inverse distance weighting factor. NOA, for these purposes uses, for several years, the Cressmann method, through the application of the graphical package GRADS.

Arta's plain meteorological station network

The National Observatory of Athens in collaboration with the TEI of Arta, studied the plain of Arta and the site position are chosen in order to cover the study area. The site selection is selected according to main criteria for obtaining accurate meteorological data. Firstly, the site is chosen to be relatively exposed and away from obstructions such as buildings and trees, over earth surface or short grass. The temperature and humidity sensors as well as the rain gauge are mounted at 2 meters and the anemometer at 3 meters above ground. Furthermore, the solar as well as ultraviolet sensors are mounted approximately at 2 meters above ground away from shadows.

The second criterion is to make the 10-min meteorological observations available, in a real-time environment to a wide variety of internet users and primarily the data transmission using communications systems to relay data back to the center server of National Observatory of Athens. For this reason, private or public sectors are chosen to host meteorological stations ensuring the stable internet connections as well as they are relatively secured. Information about the final positions of the meteorological stations is given in Table 16 as well as in Fig. 47.

Table 16 List of the meteorological stations and corresponding geographical information

Station	**Latitude (degrees)**	**Longitude (degrees)**	**Elevation (m)**
Kostakioi	39.121797	20.9467333	7
Gefyra Kalogirou	39.172316	20.892165	8
Foteino	39.134203	21.108202	510
Kopraina	39.03866	21.07444	1
Kalovatos	39.12073	20.91134	6
Psathotopi	39.071888	20.96672	0
Flampoura	39.07635	20.76173	10
Pantanassa	39.235484	20.865280	45
Kolomodia	39.08772	20.97194	2

The wireless Davis Vantage PRO2 automatic meteorological stations are used. Davis Company provides low cost category meteorological station that can supply accurate and reliable data (Burt, 2009). A meteorological station consists of: a three-cup anemometer and wind vane, temperature and humidity sensors placed into a fan aspirated shield, rain gauge, solar and ultraviolet sensors. Moreover, the pressure sensor is integral to the station display unit.

Fig. 47 Location of the ground meteorological station over the plain of Arta

Additional meteorological stations

The National Observatory of Athens (NOA) automatic meteorological stations network consists of 300 meteorological stations covering the major part of Greece. At the study area two meteorological stations of NOA network have been already sited at Vlacherna (Arta) and Kompoti region since 2006, and 2008, respectively (Table 17). Moreover, solar radiation data for both stations is available providing similar meteorological data with the rest stations over the plain of Arta. For the project needs, the data from these stations will be used in order to cover larger area over the plain. The locations of the eleven meteorological stations are presented in Fig. 48.

Table 17 Position and geographical information of NOA stations at the plain of Arta

Station	**Latitude (degrees)**	**Longitude (degrees)**	**Elevation (m)**
Vlacherna (Arta)	39.1725	20.999167	50
Kompoti	39.166667	21.133333	75

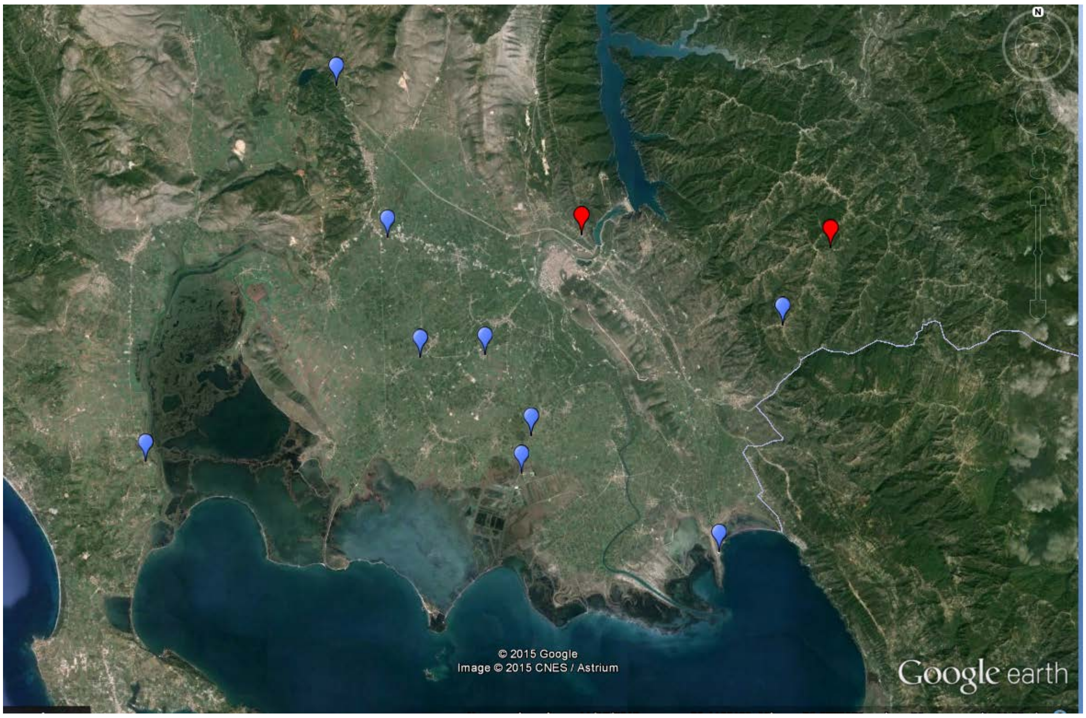


Fig. 48 Location of the eleven meteorological stations at the plain of Arta. Blue balloons represent the location of the meteorological stations which are placed in the frame of IRMA project, and red balloons the NOA stations.

Adaptation of data provided by the automatic stations

The National Observatory of Athens (NOA) provides data from its stations to IRMA at 10-min intervals. All the necessary procedures are set up in order the data to be ingested automatically to the IRMA interface.

Forecast data

The National Observatory of Athens (NOA) provides daily forecast data for 3 days for the area around Arta. Figure 5 presents the 9x7 grid (63 points in total) for which all basic meteorological parameters (including rain forecast) are provided at 3-h steps. The corresponding file is given in the following URL:

http://www.meteo.gr/customs/IRMA.txt

The forecasts are provided by Grid 2 of BOLAM model, described in detail in Section1 of this document. The procedure is fully automated and the file is ingested automatically to the IRMA interface.

The provision of data will continue for 5 years, according to the signed contract.

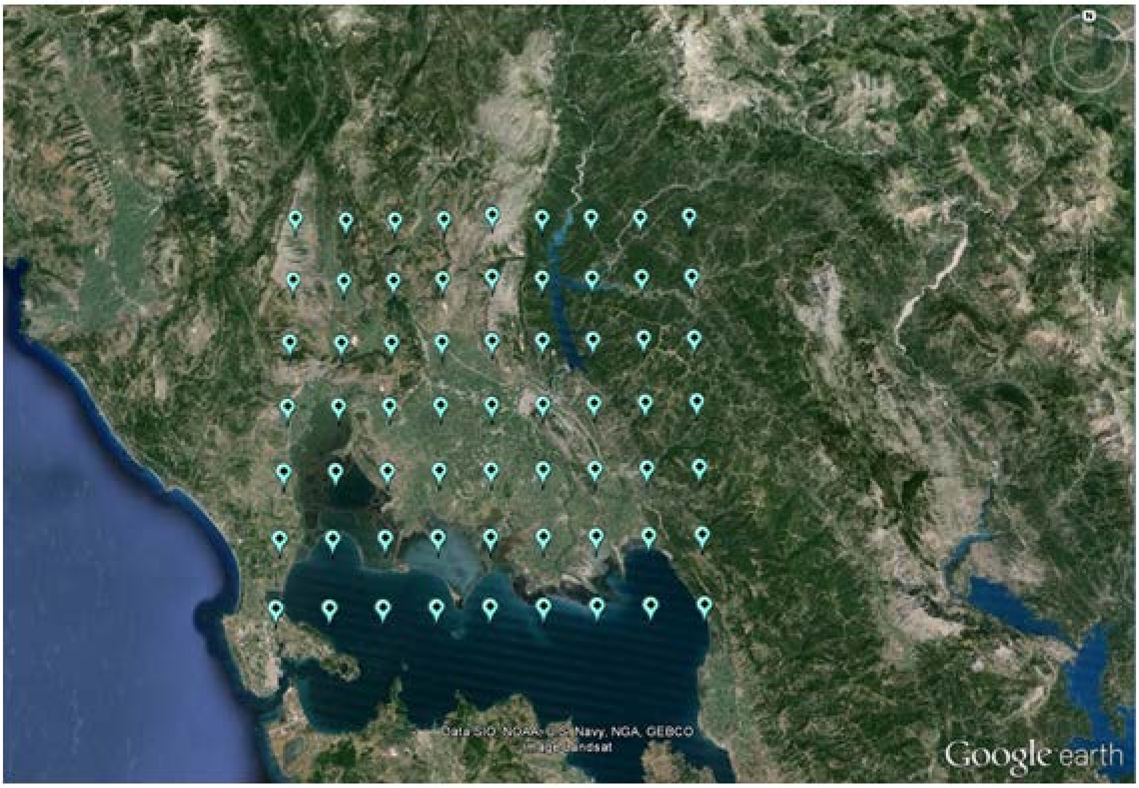


Fig. 49 Forecast 9x7 grid provided daily by BOLAM model.

Some final considerations

Negative ET values at the irrigation budgets

Users may be intrigued the appearance of negative values at the ETc[4] adj (mm) column of the Irrigation Report table. According to FAO paper 56 (Allen et al., 1998), it is even possible to obtain negative values for ETo on some winter days where the longwave radiation from the surface is large and the vapor. It also refers that by assuming that the topsoil is at field capacity following heavy rain or irrigation, the minimum value for the depletion De,i is zero so it is Dc= Dp+ETc-P-Irr and if Dc is negative, then set it to 0.0. Also according to ASCE (2005), values calculated for reference ET for nighttime hours occasionally take on negative values. In practice, the user may wish to set negative values to zero before summing over the 24-hour period. However, in some situations, negative hourly computed ET may indicate some condensation of vapor during periods of early morning dew and should therefore be registered as negative during the summing of 24h ET. In other situations, negative hourly ET during nighttime reflect the uncertainties in some parameter estimates including Rn and assumptions implicit to the final equation. The impact of hourly values on ET summed over daily periods is usually less than a few percent and in general, it may be appropriate to retain the negative values. Negative nighttime values are also reported in a number of other papers (i.e. Alexandris and Kerkides, 2003).

Special micro-irrigation reduction factors

The need to apply for inserting special factors in the scheduling calculations can be covered using the irrigation efficiency factor. This can be changed by the user through the Field (or Update Field for an existing field), when Use Custom Parameters mode has been activated (the relevant selection box must be ticked).

A good example of such need is the ET microirrigation reduction factor (r) = Percentage of soil surface that is shaded by plants during midday/0.85, having 1 as maximum value.

The irrigation optimizer approach

Estimation of irrigation needs

The irrigation needs will be estimated based on an approach that is called root zone soil water depletion, which is a simplified soil water balance based on an initial soil moisture condition and runs for a specified time period.

The basis for the calculations is the following formula (Allen et al., 1998):

$$D_{r,i} = D_{r,i-1} - (P_i - RO_i) - IR_{n,i} - CR_i + ET_{c,i} + DP_i \quad (2)$$

where i is the current time period (i.e. the current day, or hour), $D_{r,i}$ is the root zone depletion at the end of the previous time period (mm), P_i is the precipitation (mm), RO_i is the runoff (mm), $IR_{n,i}$ is the net irrigation depth (mm), CR_i is the capillary rise (mm), $ET_{c,i}$ is the crop evapotranspiration (mm) and DP_i is the water loss through deep percolation (mm).

[4] Crop Evapotranspiration

The following limits were imposed on $D_{r,i}$:

$$\Theta_s <= D_{r,i} <= TAW \quad (3)$$

where Θ_s is the soil moisture at saturation (mm) and TAW is the total available soil water (mm), which is the difference between Field Capacity (FC) and Permanent Wilting Point (PWP)), i.e.:

$$TAW = FC - PWP \quad (4)$$

This approach is different than the one proposed by Allen et al., 1998 since according to them $D_{r,i}$ is always positive.

RO_i equals the amount of water that exceeds soil moisture at saturation after heavy rain, i.e.:

$$RO_i = P_i + \Theta_{i-1} - \Theta_s \text{ when } (P_i + \Theta_{i-1} - \Theta_s) > 0 \quad (5)$$

where Θ_{i-1} is the soil moisture at the previous time step. CR_i and DP_i are considered equal, since in the case of the Arta plain there is a shallow water table and equilibrium between them is considered.

So equation 1 becomes:

$$D_{r,i} = D_{r,i-1} - P_i - IR_{n,i} + ET_{c,i} + RO_i \quad (6)$$

$ET_{c,i}$ is calculated using crop coefficient approach by multiplying reference evapotranspiration with the appropriate crop coefficient Kc (Allen et al., 1998).

Each time the user irrigates, the initial depletion derives from the provided irrigation water volume. An essential simplifying assumption of this method is that each time we irrigate without providing the irrigation water volume, we assume that enough water was applied in order for the soil moisture to reach FC, i.e. zero depletion. Therefore, in this case we have $D_{r,1}=0$, for i=1.

Soil moisture (Θ_i) and depletion are related with this formula:

$$\Theta_i = \Theta_0 - D_{r,i} + IR_{n,i} \quad (7)$$

where Θ_0 is the initial soil moisture. Since the initial soil moisture is provided, $D_{r,1}$ is also known.

$D_{r,i}$ given, irrigation is triggered when the following condition is met:

$$D_{r,i} \geq RAW \quad (8)$$

where RAW is the readily available soil water calculated from TAW:

$$RAW = MAD \times TAW \quad (9)$$

depending on the maximum allowed depletion (MAD).

In this case, the net irrigation depth ($IR_{n,i}$) is set equal to the corresponding root zone depletion from the previous time step, therefore:

$$IR_{n,i} = D_{r,i-1} \quad (10)$$

So for the next time step the root zone depletion is calculated as:

$$D_{r,i} = P_i + ET_{c,i} + RO_i \quad (11)$$

The system will take into account historical (from the system's stations), forecasts of the necessary agrometeorological data along with soil water information, in order to estimate the above mentioned soil water balance variables throughout the study area.

Irrigation optimizer

Irrigation frequency is an essential parameter for irrigation systems design and is defined as the frequency of applying water to a particular crop at a certain stage of growth and is expressed in days. The maximum irrigation frequency (MF), in days, is estimated as:

$$MF = RAW / ET_c \tag{12}$$

where RAW (mm) is the readily available soil water and ET_c is the crop evapotranspiration (mm/day).

However, the number of days between two successive irrigation events depends also on:

a. The irrigation strategy and practices that each farmer follows
b. Water availability, especially in collective irrigation systems
c. The size of the irrigation equipment
d. Other farm and crop tasks that need to be carried out at the same time

Based on the above, the actual irrigation frequency is always less or equal than the maximum irrigation frequency and is hereby defined as the practical irrigation frequency (PF).

In this context, we introduce a factor named: "Irrigation Optimizer - IRT" defined as the ratio of practical to maximum irrigation frequency:

$$IRT = PF / MF, \text{ with } 0.1 \leq IRT \leq 1 \tag{13}$$

So, Eq. 9 now becomes:

$$IR_{n,i} = IRT \times D_{r,i-1} \tag{14}$$

IRT's default value is set to 0.5, indicating that the next irrigation event should take place at the 50% of the maximum irrigation frequency and with the half of the calculated $IR_{n,i}$.
By implementing IRT, the user will be able to experiment with several alternative solutions in order to conclude to the best irrigation strategy, depending on the given conditions.

As a rule of thumb, small values of IRT result in frequent irrigations with smaller water amounts, while IRT values close to 1 result in infrequent irrigations with larger water amounts, close to RAW.

WCS-WMS services

The system can provide both Web Mapping Serivces (WMS) and Web Coverage Services (WCS). As presented in Fig. 50, meteorological data information will be uploaded in the ENHYDRIS database, where aggregation to hourly and daily time scales will take place. The map presentation of the different variables, in daily time scale, that are involved in the irrigation requirements methodology presented above, such as: Rainfall, Potential Evapotranspiration, Humidity, Temperature, Wind speed and Solar Radiation, with high spatial resolution of 70×70 m grid.

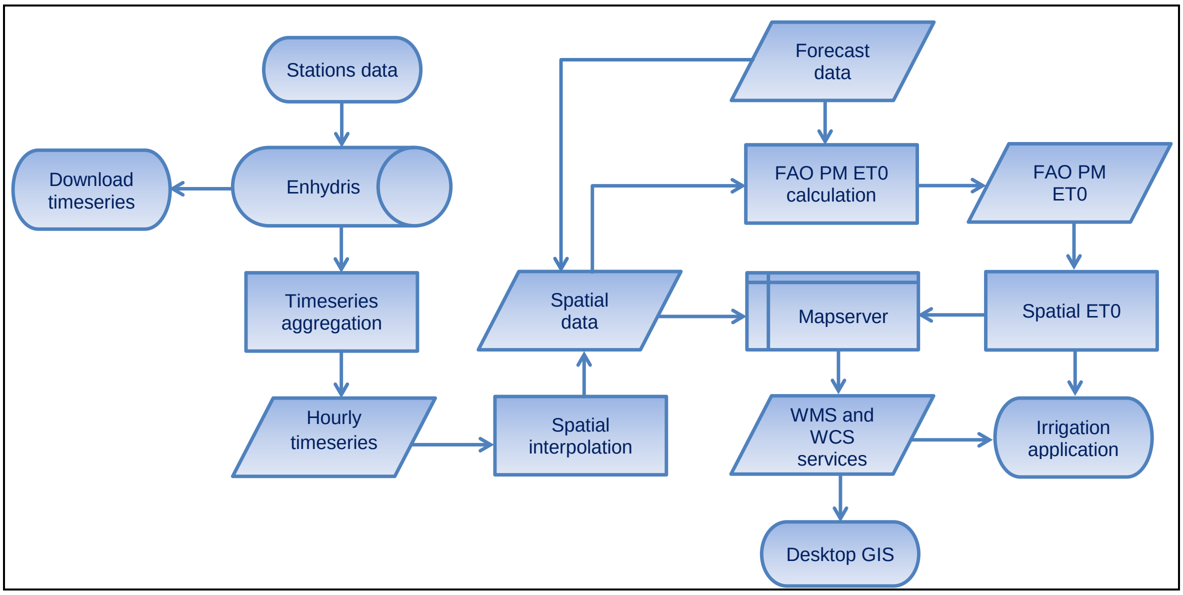


Fig. 50 Flowchart of IRMA_SYS main calculation modules prior to the irrigation application

The maps will be produced by implementing the Inverse Distance Weighting method for spatial interpolation, found in the GDAL library - Geospatial Data Abstraction Library (http://www.gdal.org/).

The system provides both Web Mapping Services (WMS) and Web Coverage Services (WCS), based on a Mapserver (http://mapserver.org/) implementation.

Both services are hosted at:

1. Historical data: http://arta.irrigation-management.eu/mapserver-historical.
2. Forecast data: http://megdobas.irrigation-management.eu/cgi-bin/mapserver?MAP=/var/cache/pthelma/mapserver-forecast.map

The historical data are kept for a year onwards and can be accessed from a desktop GIS application for further processing.

Discussion, Conclusions and Recommendations

First of all it must be indicated than only a part of an irrigation season was available for the system evaluation and this in every case was expected to lead only to preliminary results.

In both turfgrass case studies, resulted to great water savings without significant problems regarding the looks of the turfgrass. The results can be evaluated as promising and they indicating that with proper calibration there is great potential to save water and keep very good quality too. A comparison of a number of treatments, having different set of parameters for the field would be of great value. Also a comparison against commercial sensor solutions would be very interesting.

The crops' (kiwi and tangerine) case studies were presented only to provide an idea of the potentials of the system. Typical experimental setups are needed in order to asses different set of parameters of the system and to evaluate the effects of deficit irrigation to the economic output of the cultivation.

The overall performance of the system can be characterized as promising but more evaluation work must be done during complete irrigation seasons and with multiple treatments in order to obtain solid results.

Regarding the meteorological stations, the need for stations installed at the system area is inevitable in order to get calibration values. At the other hand the number of stations could be diminished in the future.

Finally it must be stated that there is no way for efficient application of the system without actual field measurements which should at least concern the irrigation water volume.

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