European Territorial Cooperation Programme
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INVESTING IN OUR FUTURE
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Efficient Irrigation Management Tools for Agricultural Cultivations and Urban Landscapes

IRMA

WP6

Specialized research actions

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V.01

European Territorial Cooperation Programmes (ETCP)

GREECE-ITALY 2007-2013

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

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IRMA partners

LP, Lead Partner, TEIEP

Technological Educational Institution of Epirus

http://www.teiep.gr, http://research.teiep.gr

P2, AEPDE

Olympiaki S.A., Development Enterprise of the Region of Western Greece

http://www.aepde.gr

P3, INEA

Instituto Nazionale di Economia Agraria

http://www.inea.it

P4, ISPA-CNR

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P6, ROEDM

Decentralised Administration of Epirus–Western Macedonia

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A knowledge harvest and experimental evaluation report

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WP6: Specialized research actions

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

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Summary

The irrigation of landscape areas is based on both science and experience. Using scientifically approved methods, historical climatic data, estimations of plant material water needs, soil and terrain properties and irrigation system characteristics a good approximation regarding the frequency and duration of watering events can be made. In any case an on-site adjustment of this theoretical irrigation schedule has to be made. Also a fine tuning regarding seasonal weather conditions contributes significantly to the system efficiency.

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.

In the framework of the present evaluation a number of irrigation scheduling approaches were tested to develop for practical proposals. The evaluation was performed during the irrigation period of 2014 (from 1/5 up to 31/10/2014) at the Kostakii Campus of the Technological Education Institute of Epirus.

A field study was conducted at the Technological Educational Institute of Epirus (Arta, Greece) in 2014. The purpose was to investigate the water conservation potential of various scheduling approaches with and without the use of special sensors (rain, solar energy, ET and soil moisture). Tall fescue, a cool-season turfgrass, was used for the evaluation as it is considered the most commonly used lawn grass in North and Western Greece. The objectives of the study were to investigate the water conservation potential of various irrigation scheduling approaches with and without the use of special sensors and to develop relevant practical recommendations to irrigation managers and home owners.

The following treatments were applied:

- 1_C Control: irrigation controller using water budget periods
- 2_R Rain: irrigation controller using water budget periods + rain sensor
- 3_S Solar: irrigation control using solar energy (as measured by a pyranometer) integration for continuous calculation of frequency
- 4_M SoilMoisture: irrigation controller connected to soil moisture sensor
- 5_TCL: irrigation controller connected to Evapotranspiration (ET) sensor + rain sensor

A comparison of the various treatments indicated that for the irrigation period of 2014 (from 1/5 up to 31/10/2014), the 3 smart irrigation systems, namely Irritrol Climate Logic™ (treatment 5_TCL), Toro Precision™ Soil Sensor (treatment 4_M) and the TEIEP solar radiation system (treatment 3_S), provided between 35 and 40% savings when compared to a typical theoretically calculated constant irrigation schedule. The latest is the best practice that local managers and homeowners apply.

The results of the rain sensor treatment (2_R) are not compared to the others as the system was off for about 15 days due to a technical problem. If for that period we assume that the system consumed the same amount of water as the 1_C reference treatment, then the savings from a rain sensor are estimated to be at least 25%.

Even the simple Water Budget approach (treatment 1_C) provided 20%water savings.

The considerable savings for treatments 3_S and 5_TCL were not accompanied by any decline in growth or quality of the turfgrass. Treatment 4_M showed no difference regarding growth and just a small difference regarding leaf area index when compared to the reference treatment (1_C).

A very interesting result was the quick identification of the irrigation problem in treatment 2_R by the PRI. It is reasonable to think that as a typical system sums the solar energy that reaches the pyranometer in order to trigger irrigation events it irrigates independently of the condition of the cultivation. Probably a system could do something similar -but taking account of the condition of the cultivation- by using an index based on reflectance from the canopy. Also a system like this could produce alarm signals in case of problem detection.

The TEIEP solar radiation system (treatment 3_S) is already developed with the function to use solar radiation values that are provided by the IRMA_SYSTEM (IRMA WP5, Actions 5.3, 5.4 and 5.5). This will eliminate the need for an individual pyranometer for each installation.

The final outcome is that the development of a solid irrigation schedule and its application including site specific adaptations (including sensors or not) is highly recommended as the expected water savings are expected to be very significant.

Introduction

Fresh water as a major natural resource had and will continue to have, great impacts on the development of human societies (SBC, 2014). The basic goal of an irrigation manager is to apply the minimum necessary quantity of water with the maximum possible efficiency. This mission is not easy and it is much more important when we have to irrigate under water scarce conditions, which is a typical case for Mediterranean basin countries. The best possible irrigation efficiency is achieved when the least possible quantity of the water is used to replenish losses and keep soil water content at a desirable level.

According to FAO-AQUASTAT (2014), agriculture withdraws between 40-80% of freshwater, in all areas around the Mediterranean Sea, even in those that are part of the industrialized European countries (Fig. 1). According to the same agency, the average national water use rate for agricultural activities is about 40 and 70% of freshwater for Italy and Greece respectively. Of course these numbers fluctuate from region to region.

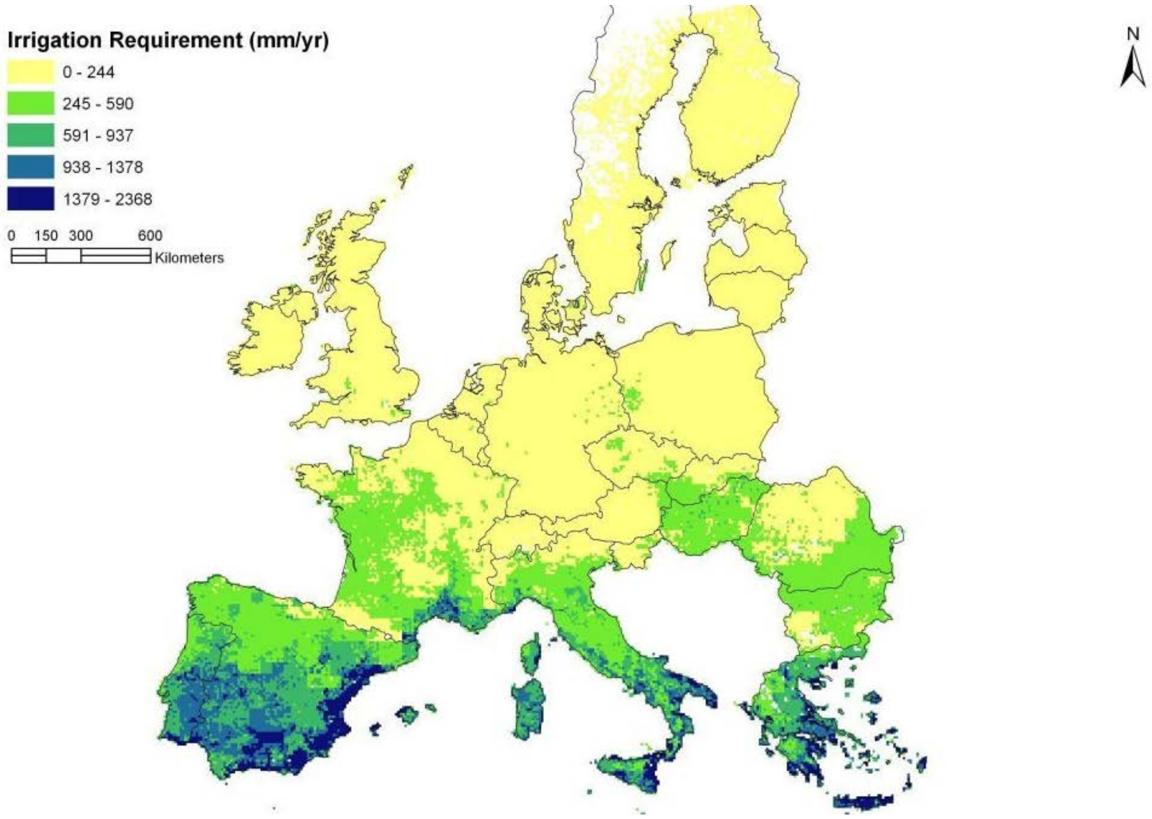


Fig. 1 Assessment of irrigation requirements in European countries (Wriedt et al, 2008)

FAO (2012) published recently a report entitled "World Agriculture: Towards 2030/2050" in the impact of irrigation on water resources using the withdrawal for irrigation (WI, the volume of water extracted from rivers, lakes and aquifers for irrigation purposes) is measured. The prediction for the Mediterranean region is a small yet continuous, annual increase until 2050. Population growth in metropolitan centers and the ongoing tourist sector development in the project region, requires that water for anticipating landscape irrigation needs (urban green and horticultural spaces, athletic fields, touristic infrastructures etc) is also taken into account, a consumer for which adequate data exist do not exist.

Fast-growing population, water scarcity and climatic alterations (NOOA, 2014), generate major problems regarding water resources management in the region. CMMC (2013) predicts a chance for a reduction between -40% to -60% of water availability for irrigation in extended areas of EU countries that are part of the Mediterranean region (Fig. 2). The EU Environment Agency (2014), in its latest irrigation water requirement assessment, states that irrigation water demand across Europe may to shift dramatically (20-45%) until 2080 and among the most vulnerable areas are expected to be those of the Mediterranean region.

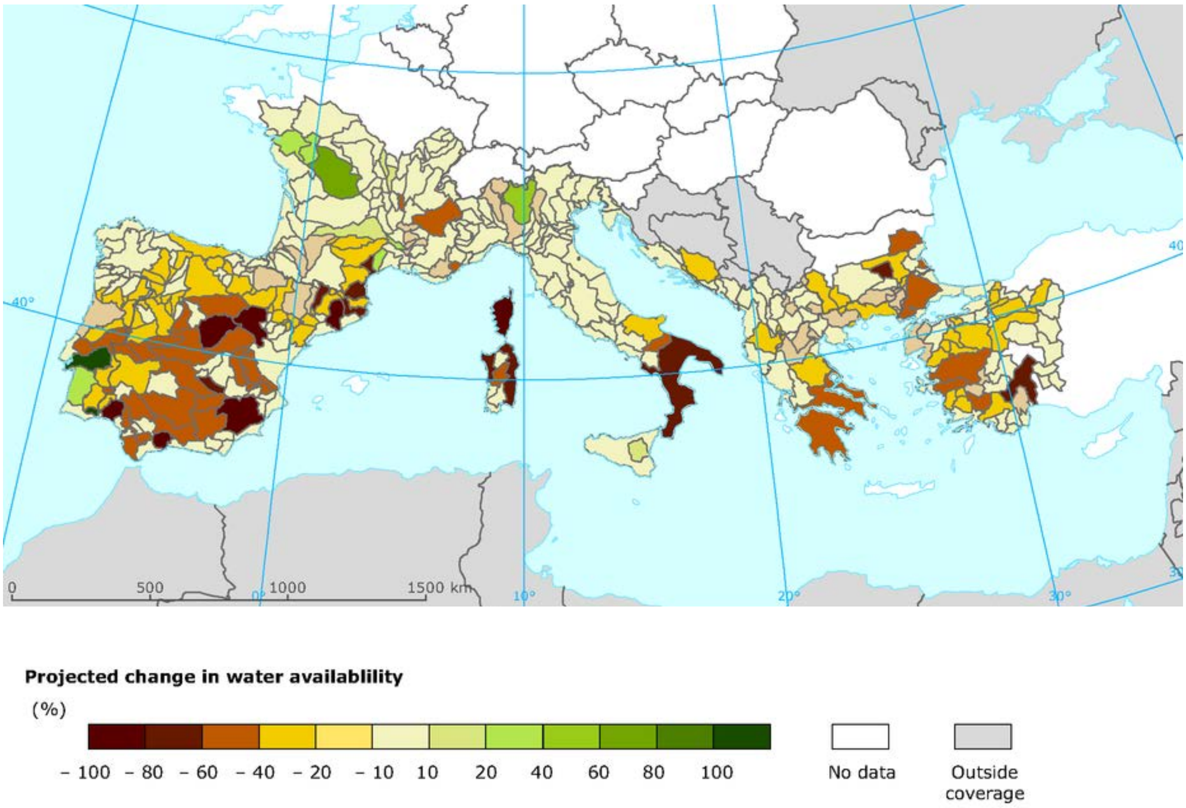


Fig. 2 Projected change in water availability for irrigation in the Mediterranean region (CMMC, 2013)

All these facts highlight the need for the development of policies and actions which will improve irrigation efficiency and on the other hand reduce the negative effects of irrigated agriculture on the environment. The relevant national and EU directives (e.g. the Environmental Impact Assessment Directive 85/337/EEC (EIA, 1985), the WFD 2000/60/EC (EU WFD, 2000), the European Landscape Convention (EU, 2000) etc) and the resulting lower level laws, decisions, standards etc create an evolving framework within which all the related efforts need to be planned and applied.

According to WFD 2000/60/EC (EU WFD, 2000), action is needed to protect waters in both qualitative and quantitative terms. Among the various measures which EU member states are proposed to adopt are the promotion of water-efficient technologies and water-saving irrigation techniques. UN

Environment Program (UNEP, 2005) states that a challenge of water-related issues for Mediterranean countries is to integrate water demand management in agriculture and to develop added value tools to optimize irrigation efficiency. In 2012, an EU report on identifying water saving potentials in the EU countries mentioned that improving water application efficiency would save 15 to 60 % of water use (BIO Intelligent Service, 2012). Cost estimates for solutions to increase supply and reducing demand vary significantly in the literature. The costs of various solutions are specific to local settings and the chosen technology. Generally, efficiency measures are cheaper than improvements to traditional water-supply infrastructure (SBC, 2014). All these facts make the optimization of efficient irrigation water use a top priority goal.

Fig. 3 The IRMA project area (source: Google Maps)

The IRMA project concept states that within the given infrastructure, agricultural (open field or under cover) and landscape, irrigation and drainage systems efficiency could be increased promptly, if their design, installation and maintenance received regular auditing procedures and more reasonable water management was applied. Adequate supply of water results in better irrigation efficiency, helps plants to avoid stress situations and boosts yield. Irrigation control involves the determination of timing, frequency and duration of each watering event.

In this framework the evaluation of various approaches regarding irrigation scheduling and the provision of relevant recommendations is expected to be of great importance. Deliverable 6.4.4: Experiments regarding sensors evaluation for irrigation management in landscaping setups (LP, Arta / Region of Epirus, Greece, Fig. 3), the activities of which are presented here and Deliverable 6.4.5 Experiments regarding sensors evaluation for irrigation management in agricultural setups (P4, Bari / Region of Puglia, Italy, Fig. 3) , reflect the contribution of IRMA project to this topic.

Experimental evaluation background

In many urban areas, landscape irrigation accounts for 50% or more of the total water use (Baum et al. 2002; Hilaire et al., 2003; Dukes et al., 2005). Automated residential irrigation systems tend to result in higher water use than non-automated systems (McCready and Dukes, 2011; Cárdenas-Lailhacar et al., 2012). This can be attributed to several factors, including a tendency to improperly program the irrigation timers during changing weather conditions. Olmsted and Dukes (2014) reported a too frequent and/or too long operating time, among the most frequent problems in the irrigation of residential gardens. If every home in the USA were equipped with an automatic irrigation system that is operated by a certified smart irrigation controller, up to 385 M€[1] in water costs and 0.45 billion m^3 of water could be saved annually (EPA, 2013).

Fig. 4 Irrigation Association, SWAT web site (IA, 2014a and b)

The increase in scheduling efficiency of an automated irrigation system provides the opportunity to conserve water resources while maintaining good landscape quality. Control technologies are available for reducing over-irrigation and include special features such as multiple programs and start times, rain delay and water budget. Also a number of sensors can be connected to modern controllers in order to provide information: rain sensors can suspend irrigation for a certain period

[1] € / US$ rate of 1/2015: 1€ = 1.13 US$

after rain, soil moisture sensors allow irrigation only when soil moisture is bellow a set threshold, pyranometers (solar radiation sensors) allow controllers to monitor solar radiation as a measure of evapotranspiration and continuously adjust the frequency of irrigation events, while evapotranspiration based controllers (ET controllers), use a series of meteorological data to calculate the actual ET at the site and use it to adjust irrigation.

A limited number of standards, guidelines and protocols regarding the evaluation of controllers and relevant sensors has been published (USEPA, 2010; IA, 2014a and b). Among them are Smart Water Application Technologies or SWAT (IA, 2014a and b; Fig. 4). a national partnership initiative in the US of water purveyors and irrigation industry representatives. It has been created to promote landscape water-use efficiency through the application of state-of-the-art irrigation technologies through offering an integral set of tools. Moreover, , a number of researchers have evaluated the efficiency of irrigation controllers and attached sensors during the last decade (Pittenger et al., 2004; Pittenger et al., 2005; Muñoz-Carpena, 2008; USDIBR, 2008; Devitt et al., 2008; McCready et al., 2009;Dukes et al., 2009a; Dukes et al., 2009b; Dukes, 2009; Davis and Dukes, 2010; McCready and Dukes, 2011; Davis and Dukes 2012; Haley and Dukes, 2012; Cárdenas-Lailhacar et al., 2012; Grabow et al., 2013).

The use of sensors for irrigation management in Greece is very limited. It has to be noted that even the fact that these technologies are not so new, simple empirical settings using fixed scheduling during the entire irrigation season is the most common practice in the evaluation area (Tsirogiannis and Triantos, 2009). In this framework, the investigation regarding the expected benefits of efficient irrigation controllers would be of great interest.

The objective of IRMA WP6, Deliverable 6.4.4. was to assess the capability of selected control technologies to adapt irrigation scheduling to actual weather conditions. The control treatment or the reference was a fixed scheduling. For this reason scheduling efficiency has been evaluated in both quantitive and qualitive means in order to determine the efficacy of each control technology. The experiment has been conducted at a new outdoor turfgrass facility which was installed at the TEIEP Kostakii Campus at Arta, Greece in 2014. The results should provide practical information to local irrigators, stakeholders, and practitioners and should contribute to the improvement of irrigation systems management in the project area.

A briefing regarding irrigation scheduling concepts and automated irrigation systems

Irrigation scheduling includes the determination of both frequency and duration of irrigation events in order to maintain soil moisture within desirable limits (Fig. 5). The goal of irrigation is to restore the water that has been "consumed" through evapotranspiration to a level close to field capacity. In some special cases (i.e. saline soil conditions) more water is provided in order to create an optimum root environment. Field capacity (FC) is the water content of the soil that is reached after a rain or adequate irrigation event and when water has been removed by the downward forces of gravity. Field capacity differs from saturation. When the soil is saturated, all the pores are filled with water. When the soil is at field capacity, the maximum water quantity can be kept in the root zone; plants do not need to consume a lot of energy in order to take up water from the soil and the spaces between the soil particles, the pores, contain both air and water. At the other end there is the permanent wilting point (PWP). This state is reached when the water content is too low for the plant to remove water from the soil. The soil structure and texture determine both its FC and PWP levels. Plant available water (AW) is the water content difference between FC and PWP (Fig. 5). When designing an irrigation schedule, one should never allow the volumetric water content to reach PWP before an irrigation event is initiated. Typically -and having in mind the special needs of each plant- irrigation is initiated when volumetric water content reaches a level between FC and PWP, which is called maximum allowable depletion (MAD). A generally approved reference regarding these calculations is FAO paper 56 (Fig. 6; Allen et al, 1998).

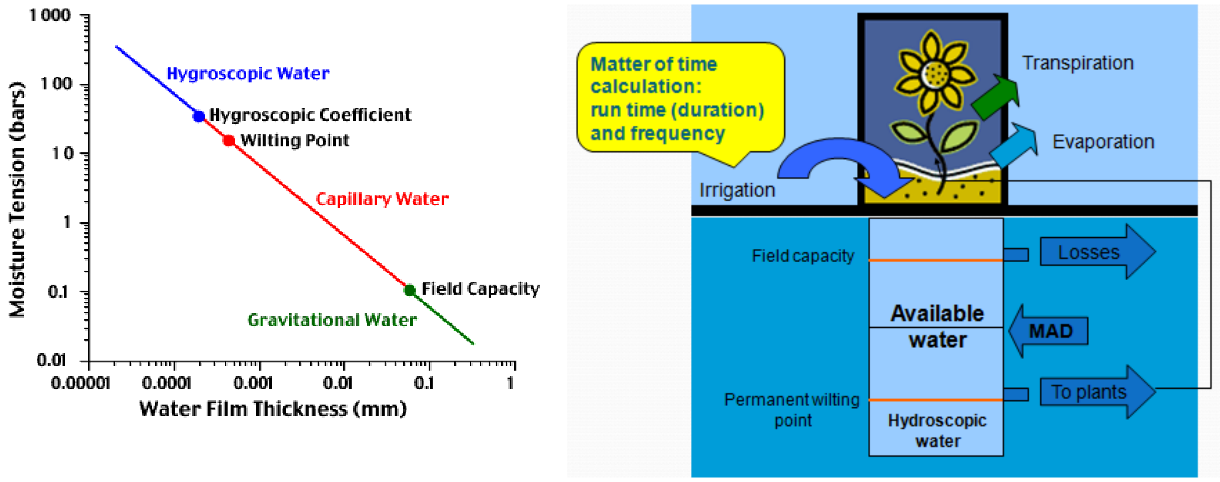


Fig. 5 Soil water content and basic concepts of irrigation scheduling

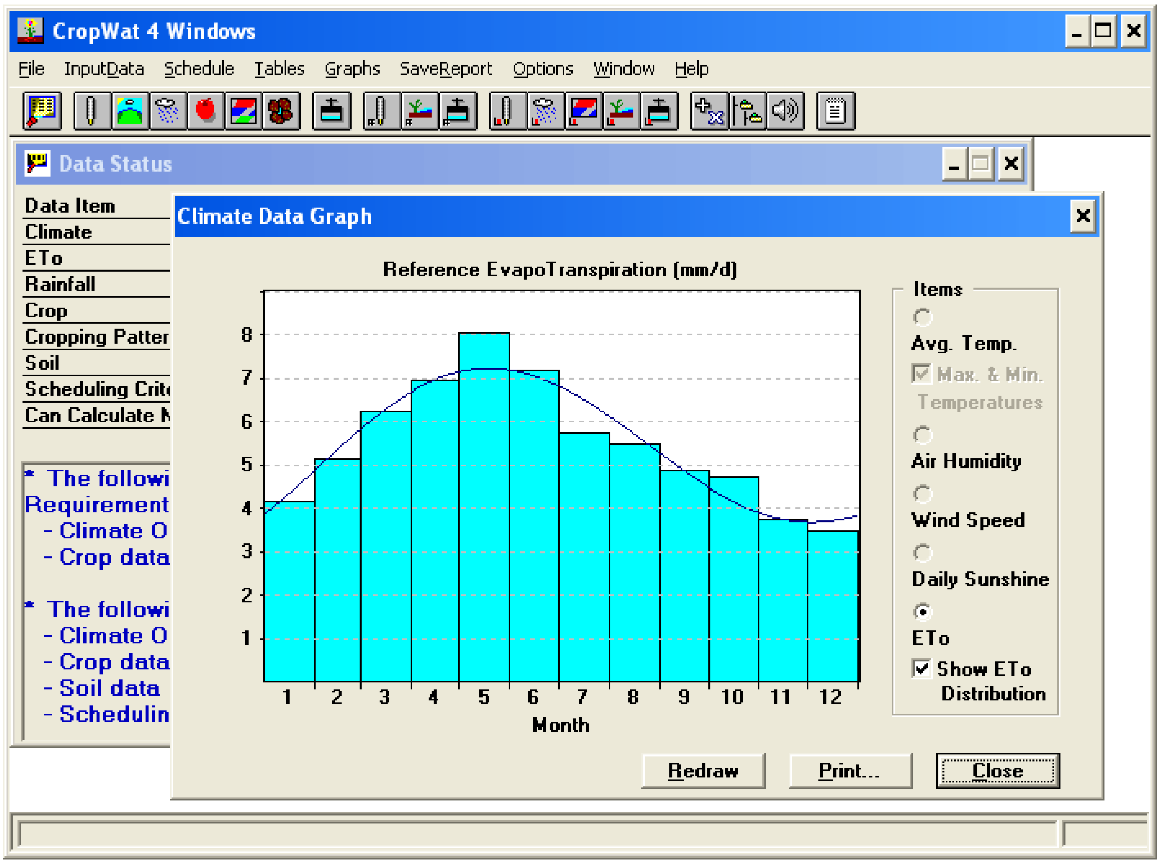


Fig. 6 Screenshot from CROPWAT, the FAO software which applies FAO paper 56 procedures

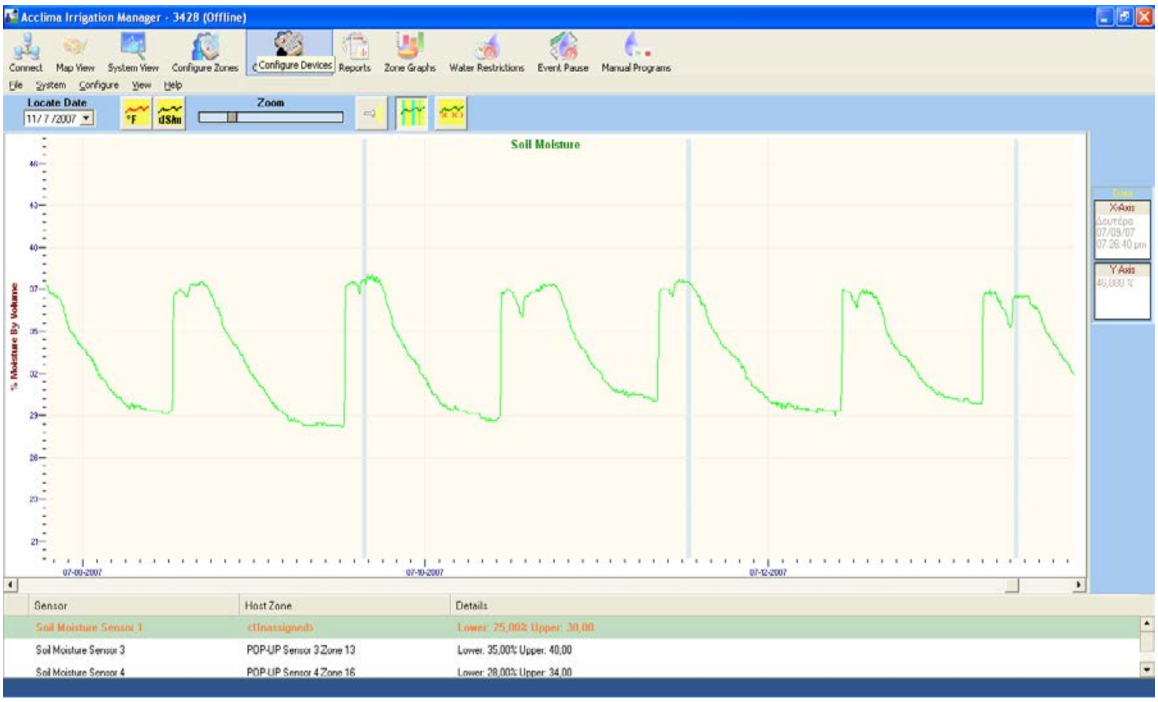


Fig. 7 Weekly soil water content fluctuation in case of irrigation

If an irrigation system is operated manually it needs constant attention by the operator. If operated automatically it, the need for attention still exist but is significantly less. Automation of an irrigation system has several positive effects. Once installed, the water distribution on fields or small-scale lawns is easier and does not have to be permanently controlled by the owner. Modern large-scale systems allow areas like parks and golf courses to be managed by only one operator. Sprinkler, drip or subsurface drip irrigation systems require pumps and other high tech-components which can also be included in the automation. The use of sensors for monitoring and alerting has become more widely used. High-tech approaches use GIS and satellites to automatically determine the water requirements of each crop parcel and schedule the irrigation system accordingly.

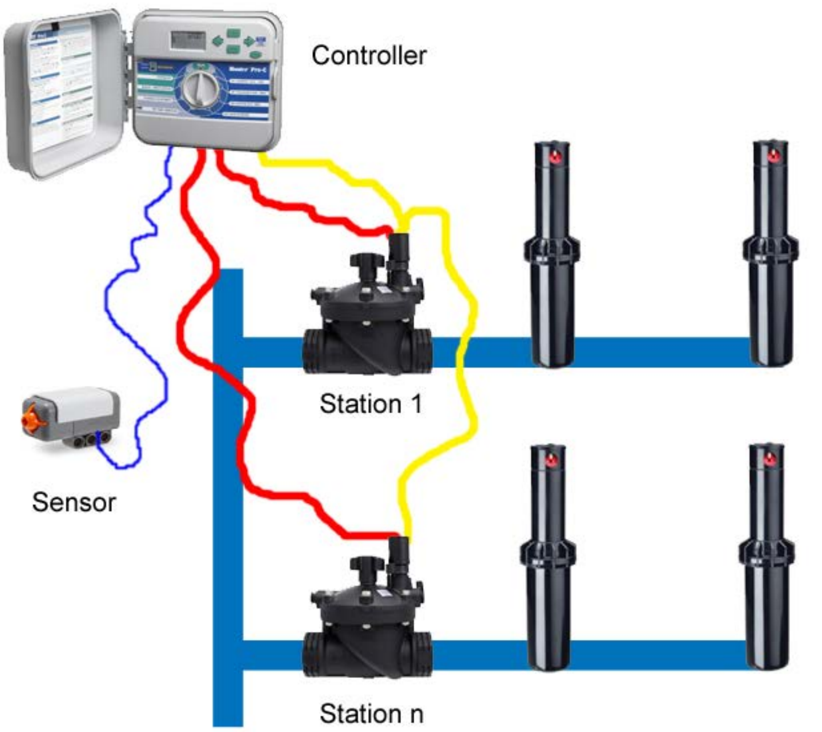


Fig. 8 Schematics of an automated irrigation system

Irrigation automation is more easily justified when a large irrigated area is divided into small segments, called zones or stations. These are irrigated in sequence to match the discharge available from the water source.

Automated irrigation decisions are typically based on:

- Predetermined timing (based on substrate, crop and system characteristics)
- Direct sensor measurements of ambient and/or soil parameters (possibly in combination with predetermined time settings)
- Direct sensor measurements of both soil and ambient environment parameters in combination with crop models)

Irrigation controllers, or just controllers or timers, make up the heart of an automated irrigation system (Fig. 8). They typically execute programs which include the start time, the frequency and the duration of control valves operation. Each valve controls the flow of water to a relevant station. Contemporary controllers include special characteristics such us rain delay, water budget and plugs for pumps and sensors.

Moving to more professional solutions one will find computer-based control systems which consist of a combination of hardware and software that acts as a supervisor with the purpose of managing irrigation and other related practices such as fertigation and maintenance (Fig. 9 and Fig. 10).

Fig. 9 Professional irrigation controller housed in special waterproof security box

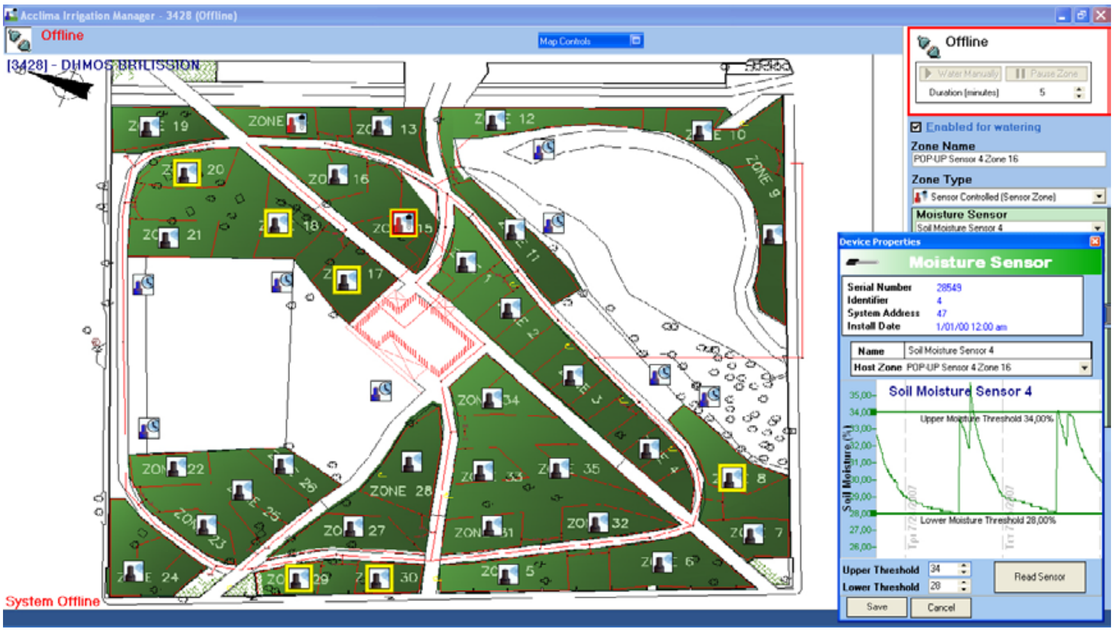


Fig. 10 Screen shot from software for central irrigation control of a landscaping setup

The most common sensors that are attached to irrigation controllers are the following (Fig. 11): rain sensor, solar energy, air and soil temperature sensors, air humidity sensor, wind speed sensor and soil moisture sensor.

Fig. 11 Sensors (rain, solar energy, air temperature and humidity, wind speed and soil moisture).

Smart Controllers

Smart-irrigation solutions lead technological advances in irrigation. Smart controllers, either weather- or sensor-based or internet-based programs provide professionals a cost-effective way to manage water usage for even their small areas, by minimizing the expense of a traditional on-site weather station. They can use computers, tablets or smartphones to monitor a controller's performance, adjust as needed, and be alerted to problems in the irrigation system. However, this doesn't mean that a smart controller is the answer to increasing an irrigation system's efficiency. Most irrigation specialists will tell you that upgrading the distribution system should take precedence over installing a smart controller.

Useful and practical information regarding smart control or irrigation systems and relevant sensors is provided by Irrigation Association (USA) in its special "Smart" Water Application Technologies webpage (http://www.irrigation.org/swat/). This page also includes testing results regarding controllers and sensors.

The following list includes some of the most popular smart controllers:

- Weathermatic SmartLink
    - Cloud-Based irrigation management (http://www.smartlinknetwork.com/)
- Rainbird ET manager

  - Receives ET related data from the nearest meteo system node (http://www.rainbird.com/landscape/products/controllers/ETmanager.htm)
- Rainbird SiteControl
  - A interactive central control system for single contiguous site applications (http://www.rainbird.com/landscape/products/central/SiteControl.htm)
- Toro / Irritrol Climate Logic
  - Uses a mini meteorological station to adjust the percentage of irrigation duration (http://www.irritrol.com/sensors_climatelogic.aspx)
- Hunter Solar-Sync:
  - This is a pyranometer – solar power integrator (http://www.hunterindustries.com/irrigation-product/sensors/solar-sync)

There are a vast number of innovative smart controllers available. One can find some interesting examples at: http://postscapes.com/smart-irrigation-controllers.

Objectives

A field study was conducted at the Technological Educational Institute of Epirus (Arta, Greece) in 2014. The purpose was to investigate the water conservation potential of various scheduling approaches with and without the use of special sensors (rain, solar energy, ET and soil moisture).

Tall fescue, a cool-season turfgrass, was used for the evaluation as it is considered the most commonly used lawn grass in North and Western Greece.

The objectives of the study were to investigate the water conservation potential of various irrigation scheduling approaches with and without the use of special sensors and to develop relevant practical recommendations to irrigation managers and home owners.

This report presents the framework and the findings of the study. A research paper will follow. It will be based on the report and it will contain all the appropriate scientific documentation.

Materials and Methods

Location and climate

The field experiment was conducted from May to September 2014 at TEIEP Kostakii Campus, 7km SW of the city of Arta in Greece (Fig. 12; lat. 39° 70' N, long. 20° 56' E / WGS84). The Arta's climate is of Mediterranean type with mild and rainy winters and hot and dry summers with occasional rain events (Fig. 13).

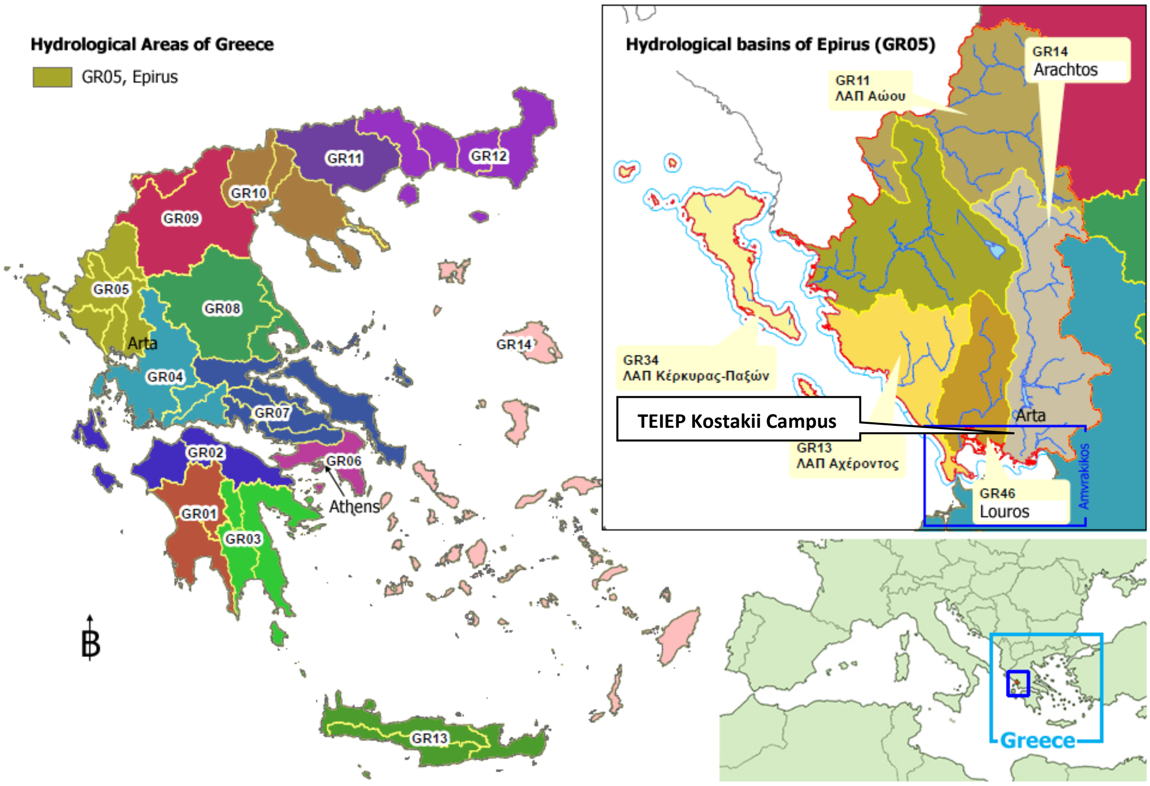


Fig. 12 Location of Arta (GR##, is the hydrological partitioning according to EU WFD (2000)

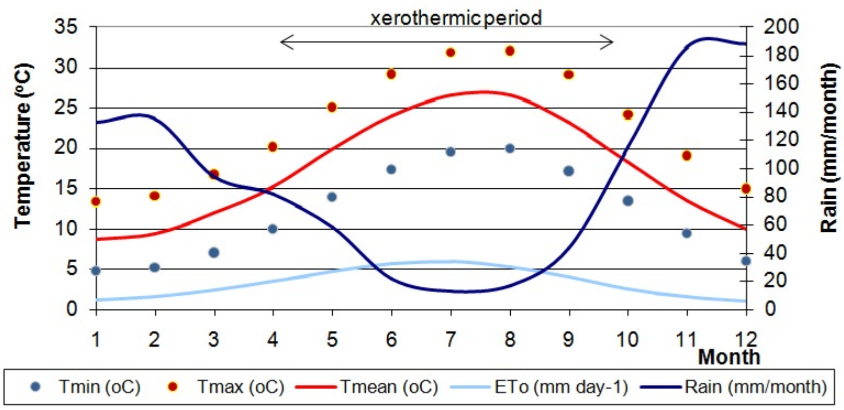


Fig. 13 Omvrothermic diagram (Bagnouls-Gaussen diagram from Nassi o Di Nasso et al., 2013) of Arta Greece (based on climatic facts of HNMS (2014))

Fig. 14 Aerial view of TEIEP Kostakii Campus (GoogleEarth, 2014)

Standards followed

The following standards where followed during the experiment:

- Laying readymade lawn turf (sod) - Hellenic Technical Specification TP 1501-10-05-02-02 (ELOT, 2009a)
- Construction of plant irrigation networks - Hellenic Technical Specification TP 1501-10-08-01-00 (ELOT, 2009b)
- Electric motor pumps for water supply and irrigation pumping stations - Hellenic Technical Specification TP 1501-08-08-02-00 (ELOT, 2009c)
- Irrigation of plants - Hellenic Technical Specification TP 1501-10-06-02-01 (ELOT, 2009d)
- Irrigation of lawn, ground cover plants and slope cover plants - Hellenic Technical Specification TP 1501-10-06-02-02 (ELOT, 2009e)
- Application of fertilizers - Hellenic Technical Specification TP 1501-10-06-03-00 (ELOT, 2009f)
- Lawn mowing - Hellenic Technical Specification TP 1501-10-06-04-03 (ELOT, 2009g)

- Plant protection - Hellenic Technical Specification TP 1501-10-06-05-00 (ELOT, 2009h)
- Weed control methods - Hellenic Technical Specification TP 1501-10-06-06-00 (ELOT, 2009i)
- Lawn improvement - Hellenic Technical Specification TP 1501-10-06-08-00 (ELOT, 2009k)
- Determination of standards for golf fields (GMT, 2014)
- Determination of minimum and maximum limits of the necessary quantities for the sustainable use of irrigation water (GMA, 1989)
- Modernisation of the methodology used for the calculation of plant water needs based on relevant studies and adaptation to Greek conditions (GMA, 1992)

Manufacturers' guidelines for sod, fertilisers, plant protection materials and irrigation system components were also taken into account.

The new ASABE's Landscape Irrigation Sprinkler and Emitter Standard (ASABE, 2014) was only available after the installation of the system and could only be validated.

Treatments and experimental setup

The following treatments were applied:

- 1_C Control: irrigation controller using water budget periods
- 2_R Rain: irrigation controller using water budget periods + rain sensor
- 3_S Solar: irrigation control using solar energy (as measured by a pyranometer) integration for continuous calculation of frequency
- 4_M SoilMoisture: irrigation controller connected to soil moisture sensor
- 5_TCL: irrigation controller connected to Evapotranspiration (ET) sensor + rain sensor

Each treatment was replicated 3 times which added up to 15 experimental plots / containers. Except of the 15 containers which hosted the experimental plots, an extra 2X6m container was maintained for extra turf if needed.

Each container measured 2X2m, framed by wooden lined trays of 0.22m height. Also a 0.40m depth plastic sheet was installed along the internal side of each tray in order to prevent horizontal movement of water between plots.

Indicative views and a generic design of the setup can be seen at Fig. 15 and Fig. 16.

Fig. 15 Construction of the experimental setup and a general view from NW

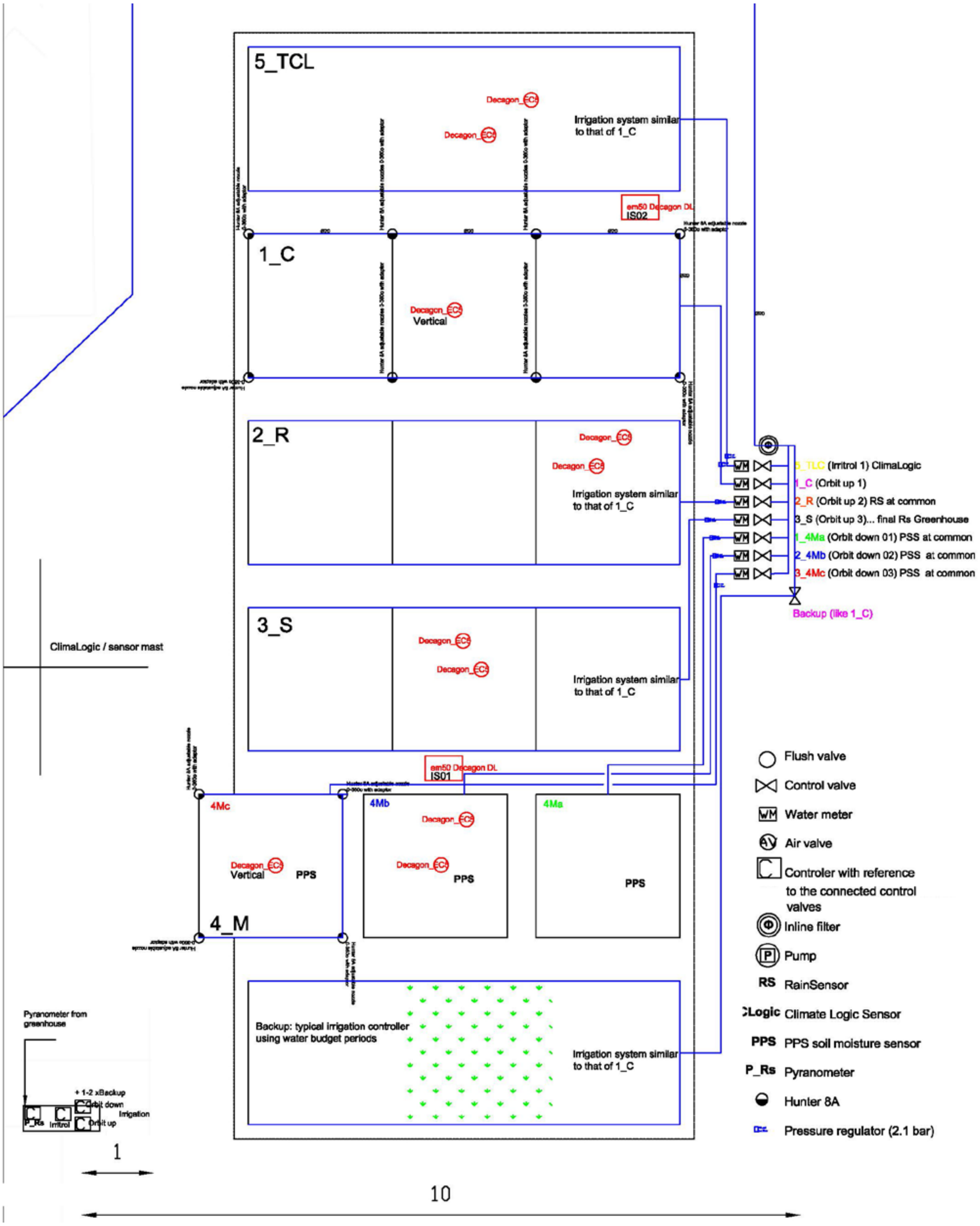


Fig. 16 Top view of the experimental setup

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 with a pH of 7.1 and an electrical conductivity of 0.42 dS m^{-1} was used for irrigation.

The following Q(lpm) | P(bar) couples were measured at the point of connection (POC): 0 | 4,50; 18,92 | 3,5; 26,50 | 2,75; 34,00 | 2,00; 37,85 | 1,40 (Fig. 17).

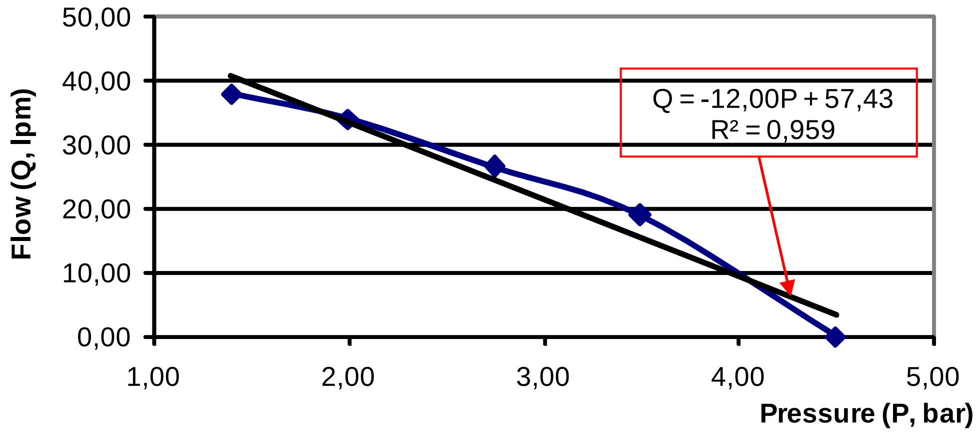


Fig. 17 Pressure, flow relationship at POC

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 (Fig. 18). Installation and establishment procedures were applied following the guidelines of the nursery (soil preparation, fertilization, initial irrigation, establishment period precautions and care etc.). The turf was considered fully established on May 10, 2014.

Fig. 18 Installation of sod

Irrigation system

For the 1_C Control, 2_R Rain, 3_S Solar: and 5_TCL treatments all replications were irrigated by a common for each treatment system. This is reasonable as the information (time or time+rain or solar radiation, or ET+rain) used to control each system did not alter among replications.

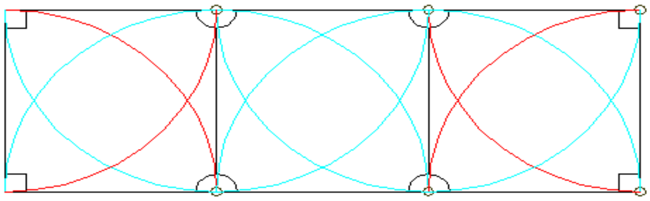


Fig. 19 Sprinkler placement in each 2x6m container

Irrigation for each of these 4 groups of 3 plots was made using 8 Hunter 8A Pro spray sprinkler heads (4 adjusted for 90^o coverage and 8 for 180^o).

For 4_M (soil moisture) treatment, as soil moisture info could vary, a separate sensor and irrigation system was used for each replication. Irrigation was applied using 4 Hunter 8A Pro spray sprinkler heads (all adjusted to 90^o coverage). For the backup container 8 Hunter 8A Pro spray sprinkler heads (4 adjusted for 90^o coverage and 8 for 180^o) were used.

All heads were placed on special adaptors at the outer face of each container (Fig. 19). 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 (1_C, 2_R, 3_S and 5_TCL) was about 13lpm and for the 2x2 systems (4_M) 4,3lpm.

Fig. 20 Control valve boxes

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 (Fig. 20).

The lower quarter distribution uniformity of the system (DUq), according to the audit procedures of IA (2012a); was found to be 68 (±3%)[2].

Irrigation was scheduled by controllers and is described in more detail the next chapter. All controllers were placed in closed boards.

[2] Standard error

Generic irrigation schedule

According to ELOT (2009e), 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.

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 UCCE and CDWR (2000), the coefficients of species (ks), density (kd) and microclimate (kmc) where estimated to be about 0.8, 1 and 1 respectively.

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

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

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

- one irrigation event every 2nd day

- about 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
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).

Plant protection

At sodding, 1kg of Pyrinex (Group 1B organophosphate insecticide) was applied as ant population was high.

All plant protection issues that have been appeared during the evaluation period were successfully resolved. More specifically:

- 13/6: the entire area was treated with Aliette (fosetyl-Al, 80%), 37gr/15L + Neotopsin (Thiophanate methyl, 70% m/m) 10gr/15L + Decis 10cc/15L (Deltamethrine 2.5% m/v) in order to treat fungal problems (*Rhizoctonia solani*, *Helminthosporium* sp and mushrooms (*Agaricus* sp and *Armillaria mellea*)).
- 18/7: the entire area was treated with a mixture of 20gr Neotopsin (Thiophanate methyl) and 5gr Flint (Trifloxystrobin) in 15L of water in order to treat fungal problems (*Rhizoctonia solani*, *Helminthosporium* sp and mushrooms (*Agaricus* sp and *Armillaria mellea*)).

Fertilisation

At sodding, COMPO Complesal Supra 21-5-10 +3MgO+B+Fe+Zn fertilizer was applied at a rate of 4kg (55 gr m^{-2}). During the course of the study, fertilizer was applied monthly at the following rates:

- 29/4, Nitrophoska special 12-12-17 (+2+8)[3], 50g m^{-2} (EuroChem Agro Hellas S.A.)
- 29/5, ENTEC 24-8-7[4], 25g m^{-2} (EuroChem Agro Hellas S.A.)
- 30/6, Nitrophoska special 24-8-7 & 12-12-17 (+2+8), 25g m^{-2}
- 26/7, Nitrophoska special 24-8-7 & 12-12-17 (+2+8), 25g m^{-2}
- 14/8, Nitrophoska perfect (15+5+20 (+2+8))[5], 25g m^{-2} (EuroChem Agro Hellas S.A.)
- 31/8, Nitrophoska perfect (15+5+20 (+2+8)), 25g m^{-2} (EuroChem Agro Hellas S.A.)
- 23/9, Nitrophoska perfect (15+5+20 (+2+8)), 25g m^{-2} (EuroChem Agro Hellas S.A.)
- 21/10, Nitrophoska perfect (15+5+20 (+2+8)), 30g m^{-2} (EuroChem Agro Hellas S.A.)

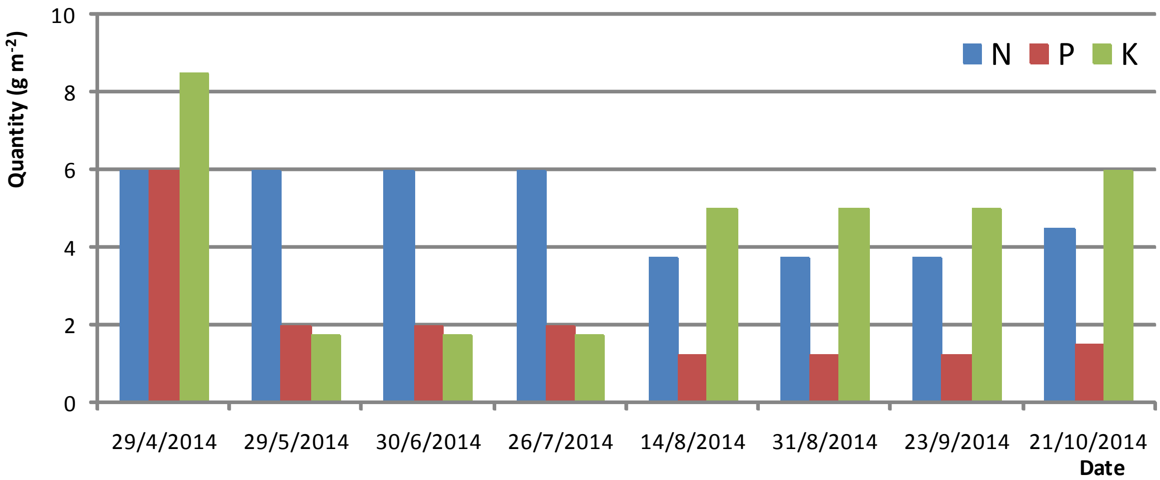


Fig. 21 Applied quantities of N, P and K

Mowing

From June 1st, 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.

[3] Nitrophoska special 12-12-17: 4.8 % N-NO_3, 7.2 % N-NH_4, neutral ammonium citrate and 7.8 % P_2O_5, 17 % K_2O
[4] ENTEC 24-8-7: 10.8% N-NO_3, 13.3% N-NH_4, neutral ammonium citrate and 5.2 % P_2O_5, 7% K_2O.
[5] Nitrophoska perfect: 7% N-NO_3, 8% N-NH_4, neutral ammonium citrate and 3.5 % P_2O_5, 20% K_2O

Sensors and irrigation scheduling

1_C Reference treatment

This treatment was considered to match expected behavior of local turf managers and homeowner's. 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 characteristics of the applied schedule were:

- one irrigation event every 2nd day
- start time at 5:30 in the morning
- 15min initial run time per irrigation event which was lowered to 11min after using data from a system audit
- water budget at 60% during the cool part of the irrigation period (1/4-31/5 and 1/9-31/10)

Fig. 22 Orbit sprinkler timer

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 70% will alter a 10-minute preset watering duration to 7 minutes.

2_R Rain sensor Treatment

Irrigating a landscape during or immediately after a rainfall event not only results in oversaturated plants and turf, but it also wastes water. For treatment 2_R the irrigation period was also divided in cool and warm section. Additionally, any irrigation was prevented after a pre-set level of rain has fallen. Once the rain passed, the rain sensor allowed the controller to resume normal irrigation. A Hunter Mini-Click Rain Sensor (Hunter Industries, USA; Fig. 23) was used for rain control, and it was adjusted to 13mm, following the recommendations of the manufacturer for the climatic conditions under consideration (Hunter, 2014). The sensor was mounted on the metal gutter of the adjacent greenhouse at a height of 3.5m.

Treatment 2_R shared the controller with 1_C, thus the available special connection for sensor was not used and the rain sensor was inset at the common wire or the relevant control valve. The sensor switch of the controller was at bypass position.

Fig. 23 Hunter Mini-Click, rain sensor

3_S Solar Energy sensor treatment

For the control of treatment 3_S, a system which was developed at TEIEP was used. The frequency of irrigation was based on solar radiation, as measured by a pyranometer (SKS1100, 350-1100nm, Skye Instruments, UK). Solar radiation (W m^{-2}) was integrated over time (Wh m^{-2}) and when energy reached a preset level irrigation was provided to the turfgrass (Fig. 24). This means that irrigation run time remained stable while frequency varied according to the time needed for solar energy to catch a preset level. A relevant system has been used for more than 7 years to irrigate the plants in the adjacent greenhouse (Tsirogiannis et al., 2010).

About 4 and 6.5 kWh day^{-1}, of solar energy are expected to reach the earth surface at the latitude of the experimental location during a sunny mid spring / fall and midsummer day respectively (Mavrogiannopoulos, 1994). Therefor the 3_S system was adjusted to the following operation schedule:

- one irrigation event every 2nd day (in other words, where 12 kWh day^{-1}, of solar energy were summed)
- start time at 5:30 in the morning
- 15min initial run time per irrigation event which was lowered to 11min after using data from a system audit

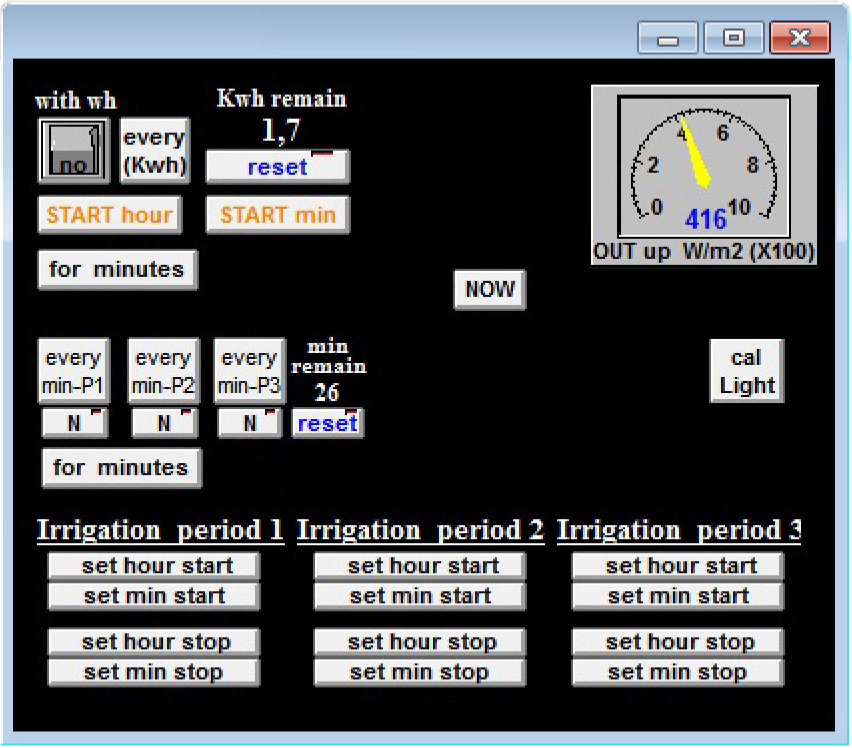


Fig. 24 Screenshot of the TEIEP irrigation control system

4_M Soil moisture sensor treatment

In 4_M treatment Toro XTRA SMART™ Precision™ soil moisture sensors (PSS) were installed and operated following the instructions of the manufacturer (TORO, 2012). A self-calibration procedure was used to determine moisture thresholds for the PSS controller. The soil moisture that was determined 24 hours after an irrigation event to near saturation was considered field capacity. Irrigation was subsequently withheld until a threshold of 50% of the field capacity was reached. This threshold was kept constant during the course of the evaluation period since turf quality of the plots never dropped below the minimum acceptable level.

The characteristics of the applied schedule were:

- one irrigation event per day (according to the suggestions of the manufacturer)
- start time at 5:30 in the morning
- 7.5min initial run time per irrigation event which was lowered to 5.5min after on-site adjustment

The schedule was applied using an Orbit sprinkler timer Model # 94881 (Orbit, 2014). As the 3 replications of 4_M treatment where connected to the same controller, the receiver of each PSS was inset at the common wire or the relevant control valve and the sensor switch of the controller was at bypass position.

The installation of each PSS was made after a uniformity audit of the system using catch - cans. The water volume that was collected in each can was used to perform a spatial interpolation using GIS (ESRI, ArcGIS) which allowed to estimate the amount of water on each point of the plot. The sensors were placed at the quarter of each replication that received the lowest amount of water.

Fig. 25 The receiver (up) and the sensor (down) of the TORO PSS system (the upper photo presents the receivers of the 3 experimental replications: A, B and C, each one of them corresponded to one sensor).

5_TCL ET station treatment

In 5_TCL treatment an Irritrol Climate Logic™ system was installed and operated following the instructions provided by the manufacturer (Irritrol, 2011). Climate Logic uses a micro weather station which monitors air temperature and relevant humidity; solar radiation and rain to determine the actual ETo.

The characteristics of the applied schedule were:

- one irrigation event every 2nd day
- start time at 5:30 in the morning
- 15min initial run time per irrigation event which was lowered to 11min after on-site adjustment

The CL-M1 receiver was connected to a compatible controller, namely an Irritrol Rain-Dial. The duration of the generic irrigation schedule event for the most unfavorable conditions, was automatically adjusted every day using the standard 3 previous day average meteorological conditions. The 3 days interval is the factory preset value. The rain sensor was adjusted to hold irrigation at 13mm.

Fig. 26 Irritrol Climate Logic system and Rain Dial controller.

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).

Fig. 27 Meteorological station

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

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

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 (Fig. 28).

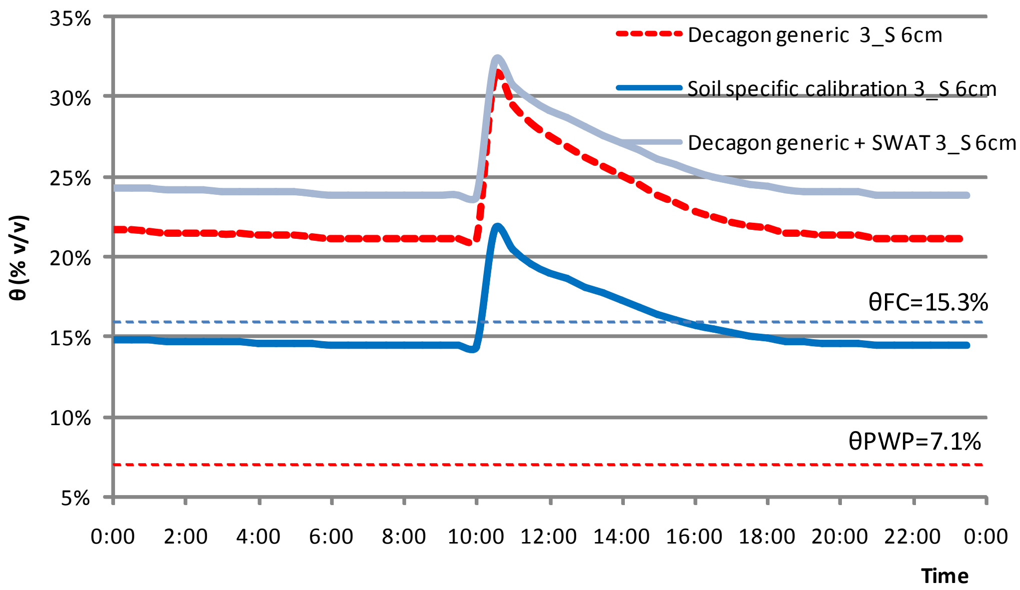


Fig. 28 Differences between signal and soil moisture reading when different equations are used (diurnal variation of volumetric water content during 20/7/2014, for 3_S treatment at 6cm depth)

For treatments 2_R, 3_S, 4_M and 5_TCL, 2 EC-5 sensors were placed at two depths (5 and 17cm) with their plane perpendicular to the soil surface (as proposed by the manufacturer; Decagon Devices, 2010). For 1_C the EC-5 sensor was placed vertically with the edges of its prongs at 10cm. An extra sensor with this kind of vertical placement was also installed for the 4_M treatment.

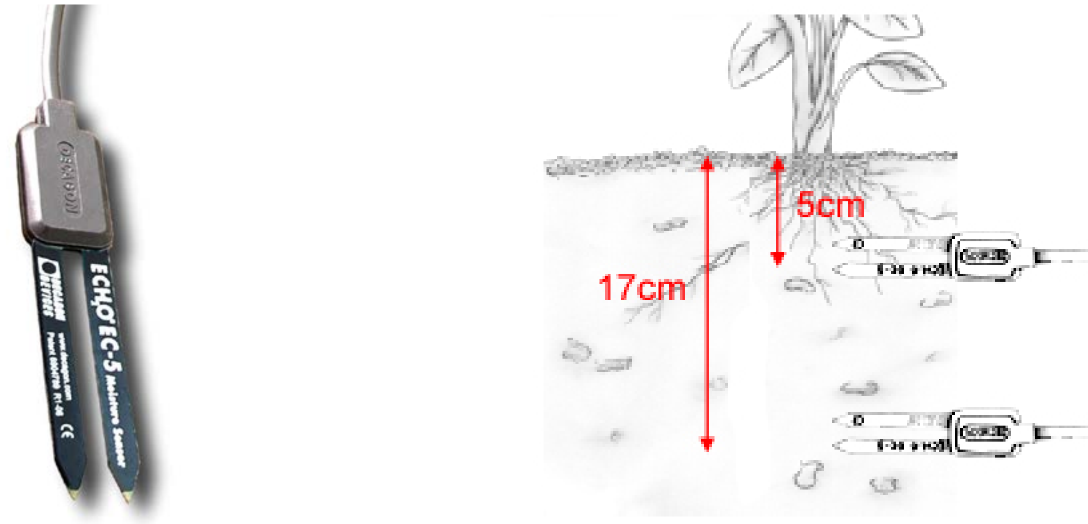


Fig. 29 The EC-5 VWC sensor and the installation depth

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

Also, as a backup measurement, soil moisture readings from 0 to 6 cm depth were recorded manually every day by means of a hand-held TDR soil moisture meter (ThetaProbe, Delta-T Devices Ltd, UK).

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.

Water consumption measurement

Measurement of the water consumption during the evaluation period was made by 1'' volumetric dry dial water meters (1L resolution) (Fig. 30). One meter was installed for each treatment, except for the 4_M one for which 1 meter was available for each replication and the measurements were registered manually every second or third day.

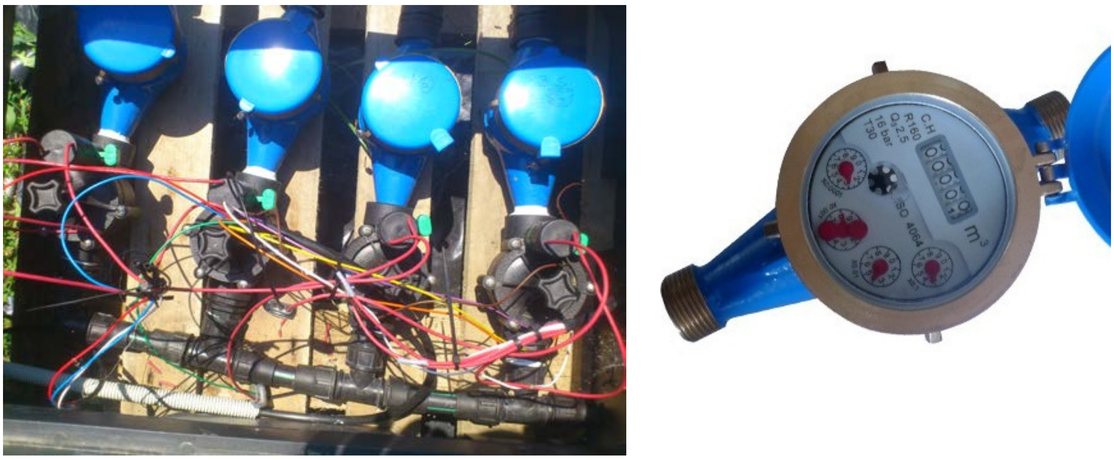


Fig. 30 Volumetric water meters (one valve box: 4 of the total 7 water meters that were installed)

Soil characteristics and root growth evaluation

Root samples were collected on monthly basis. Three random soil cores (Fig. 31) were removed from each replication using a tube sampler with a diameter of 50mm. Roots were washed and hand cleaned to separate stolons and rhizomes from roots and all other material. The roots were weighed (fresh weight), dried at 70°C for 48h and then weighed again in order to obtain their dry weight.

Fig. 31 A typical soil core

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. 32) 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. 32 Sample cuttings equipment and field procedure

Reflectance measurements for turfgrass quality evaluation

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).

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 infra red and Red is the Red region of the spectrum. The measurements were made around solar noon.

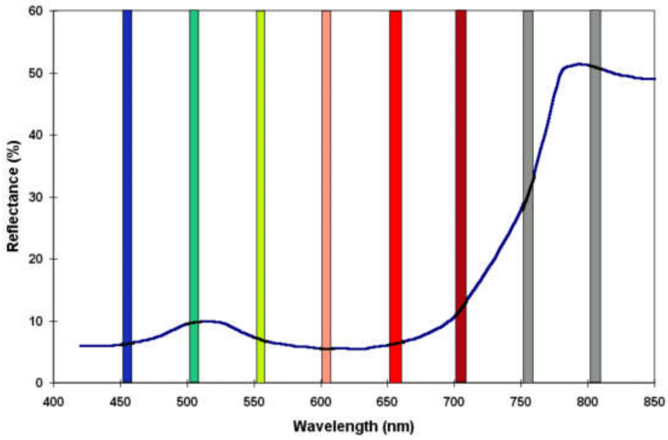


Fig. 33 Canopy reflectance measurement using CropScan and typical reflectance spectrum over grass

Other canopy reflectance measurements (NDVI and Digital Imaging)

For a certain period two other reflectance measurements were performed along with those of the CropScan device:

- A brand new NDVI Radiometer (Rugged NDVI Radiometer, Decagon Devices In.) was used for measuring NDVI as (R800 - R630) / (R800 + R630). This index can provide valuable information regarding Leaf Area Index (LAI) (Decagon Devices, 2014).

- Photos were taken randomly over each plot and averaged for calculating the percent green coverage and dark green color index (DGCI) using Digital Image Analysis (DIA). A dark chamber that was constructed at TEIEP was used for this purpose.

Measurement of canopy temperature

Canopy temperature and resistance to vapor flow were measured periodically, because of the availability of the relevant devices. For measuring the canopy temperature an infrared temperature sensor was used (IRt/c.10, Exergen Corporation, USA).

Efficiency evaluation protocols and statistical analysis methods

The Smart Water Application Technologies (SWAT) initiative began in 2002 as a collaboration of water purveyors and the irrigation industry in USA, under the auspices of the US Irrigation Association (IA, 2013a).

In 2006, the US Environmental Protection Agency (EPA) created a US national program called the WaterSense program to promote water efficiency similar to the Energy Star program for energy efficiency. In 2012, EPA began adding weather-based irrigation controllers to its program (EPA, 2014). WaterSense criteria are based on the SWAT testing protocol but include modified requirements for minimum runtimes, missing weather station data, rainfall requirements and calculating the water balance (IA, 2013a).

The Smart Water Application Technologies (SWAT) provides a number of protocols that can be used for identification, research and promotion of technological innovations and related management practices that advance the principles of efficient water use (Huck and Zoldoske, 2006).

SWAT protocols define generally applicable procedures for the overall efficacy of irrigation controllers. Examples of the various types of controllers that can be evaluated are:

1. Controllers that store historical ET data;
2. Controllers that use on-site sensor(s) as the basis for calculating real-time ET;
3. Controllers that use ET or other relevant data from remote central weather stations;
4. Controllers that use rainfall, soil moisture or other signals for controlling the execution of irrigation events and
5. Control technology that is added onto existing irrigation timers.

The protocols attempt to simulate both typical and problematic irrigation systems. They do not have a pass/fail rating. The procedure is designed to evaluate the controller's performance against an established ideal standard.

Technologies that have been evaluated in the SWAT framework of this study:

- the testing protocol for weather-based controllers begun to be developed in April 2003; and its current version is the number 8 which was approved and adopted in September 2008 (IA, 2008a and 2010)
- the development of a testing protocol for rain sensors began in April 2007; and its current version 3.0 was approved and adopted in October 2009 (IA, 2013b)
- the development of a testing protocol for soil moisture-based controllers began in April 2003; and its current version 3.0 was approved and adopted in August 2011 (IA, 2011a).

From the components that have been used in this work, the following have been evaluated according to SWAT protocols:

- Hunter Mini-Click (IA, 2012b)
- Decagon EC-5 (IA, 2008b)
- Irritrol RainDial Climate Logic (IA, 2011b)

Statistical analysis

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.

Results

Meteorological conditions

Calculated monthly ETo, precipitation rates during the experimental period (2014) and relevant climatic parameters (HNMS,2014) are presented in Table 3. Although the general global climate for the period June-August 2014 was characterized by high temperatures, the conditions for a number of European areas deviated from the general trend (NOAA,2014). The summer of 2014 had a lower ET demand and less rain during July and August when compared to the typical climatic conditions of the area (Table 3, Fig. 34 and Fig. 35).

Table 3 Climatic and meteorological information

	mm month^{-1}			
Month	**Climatic (20 y)**		**During the experimental period (2014)**	
	ETo[a]	**R[b]**	**ETo[a]**	**R[b]**
April	103.56	81.50	2.06 (±0.17)	129.83
May	145.34	58.50	3.80 (±0.17)	74.43
June	168.67	21.80	5.38 (±0.16)	18.83
July	183.29	12.60	5.22 (±0.10)	7.20
August	163.42	17.20	4.75 (±0.07)	1.80
September	119.23	43.50	3.28 (±0.11)	123.80
October	77.98	115.00	3.46 (±0.10)	157.60

[a] ETo is the daily average reference evapotranspiration as calculated according to FAO paper 56 method and [b] R is the cumulative precipitation height. The standard error of the values -when available or has sense- is provided in the parentheses.

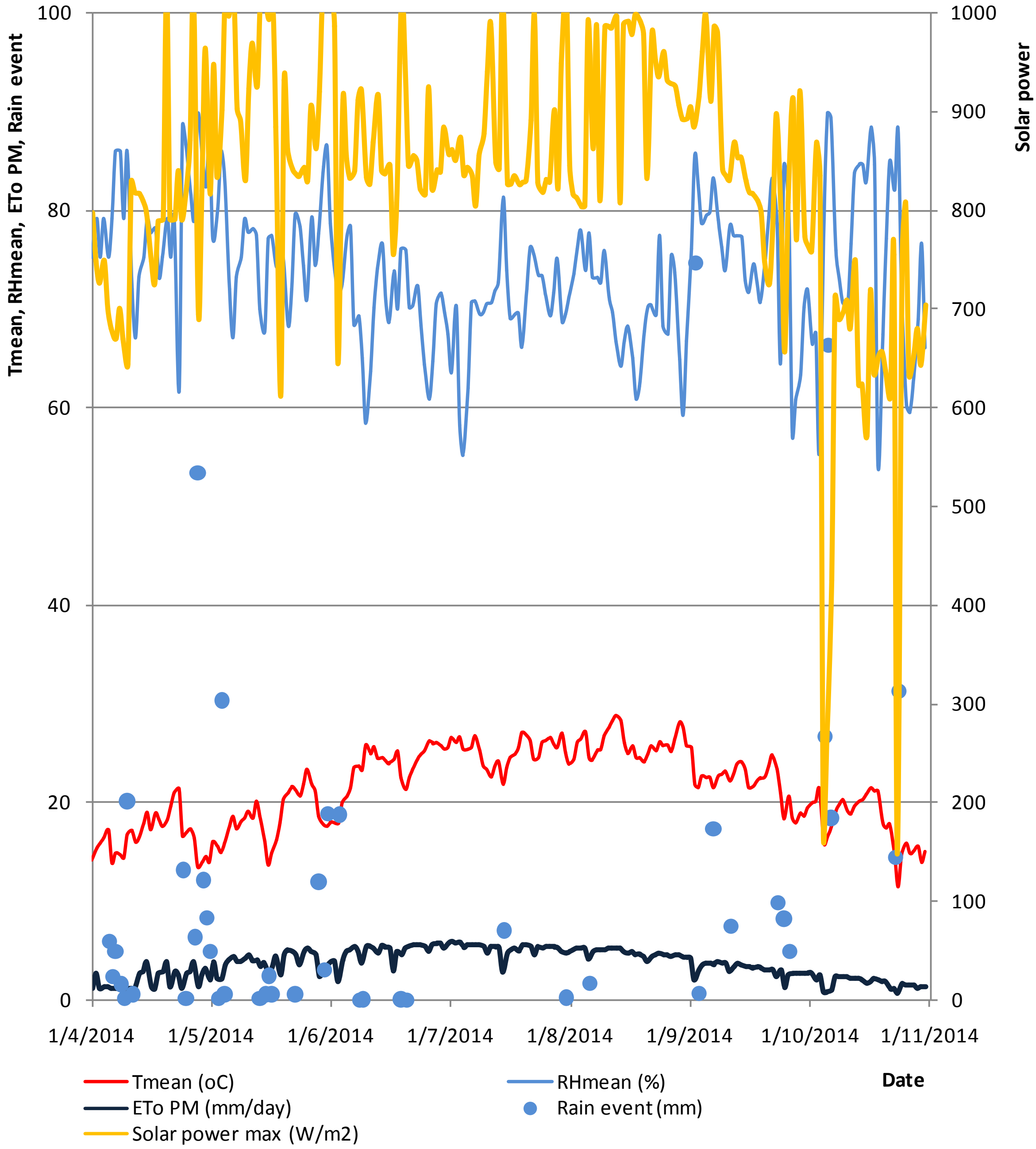


Fig. 34 Solar radiation, T, RH, ETo and Rain events during the experimental period

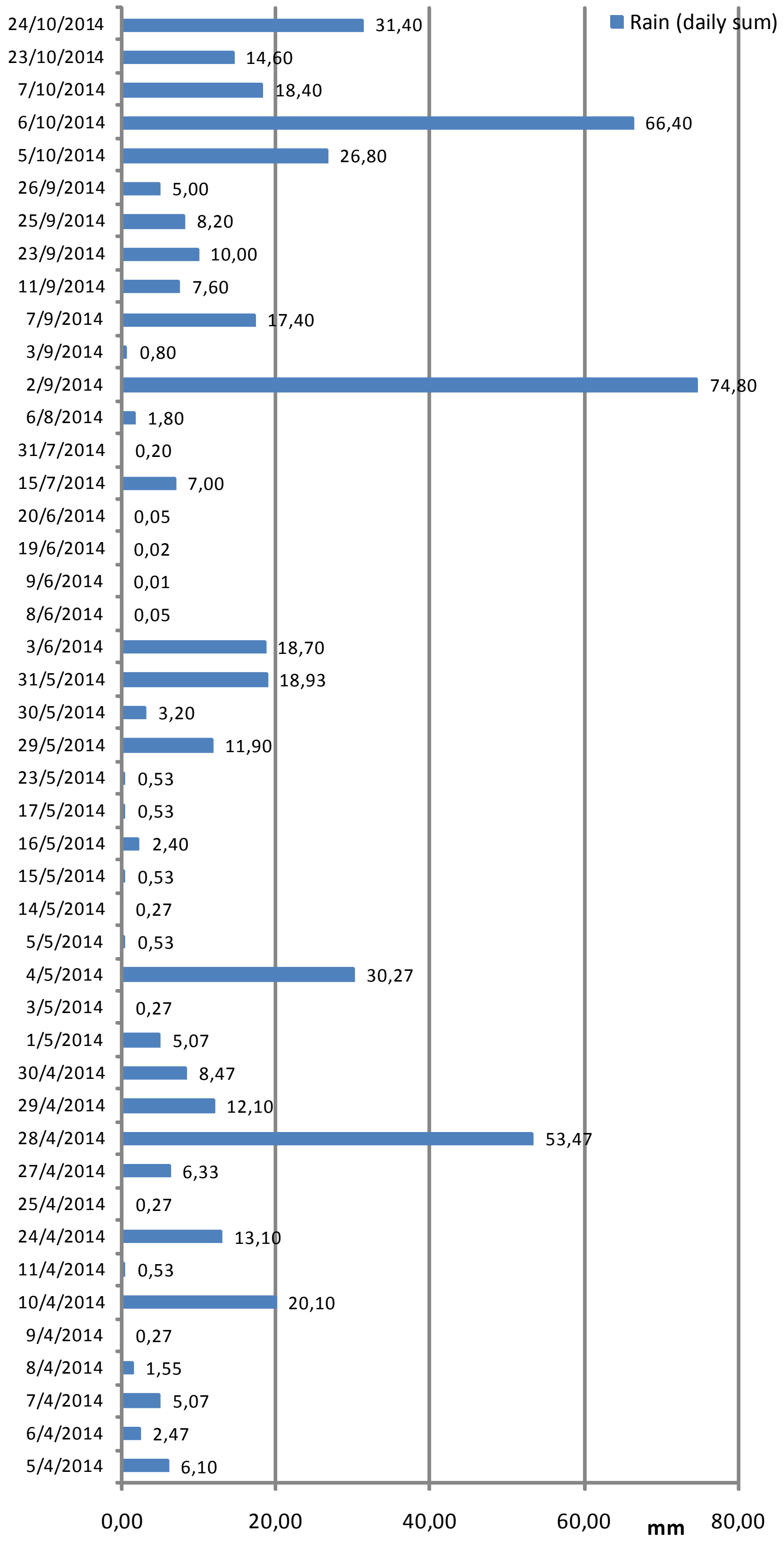
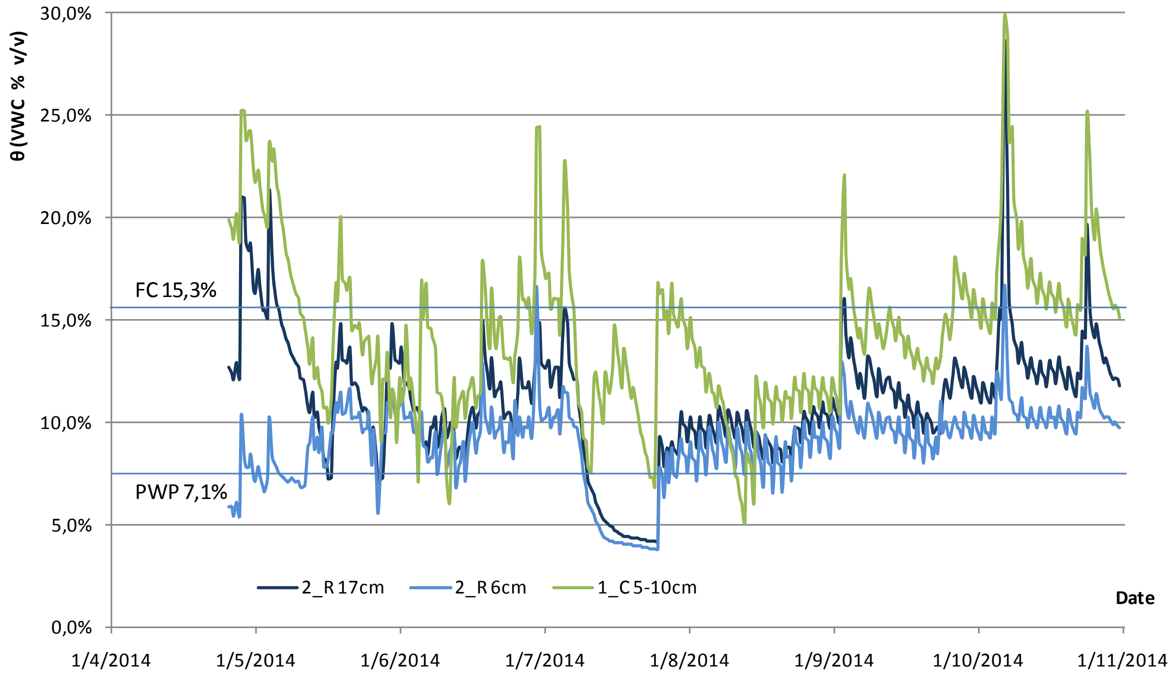


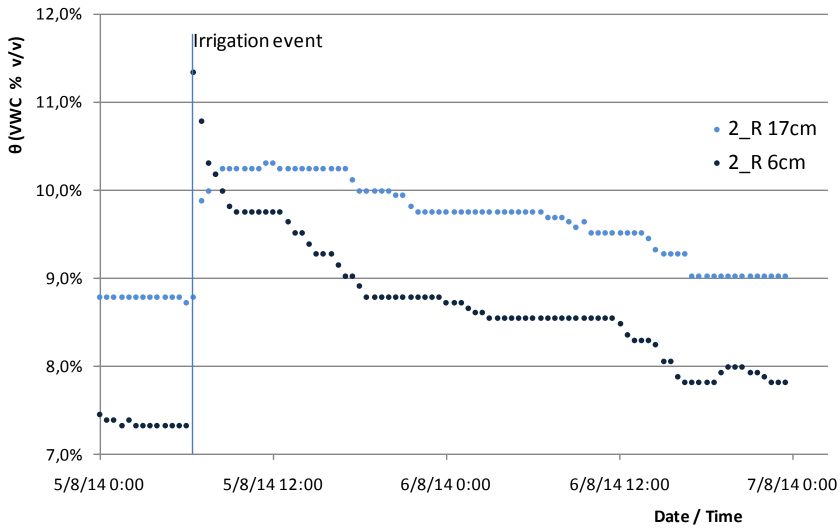
Fig. 35 Rain events that occurred during the experimental period

Soil moisture

As shown in Fig. 36, Fig. 37 and Fig. 38 soil moisture was kept in general within the targeted limits. The higher values of soil moisture for the depth of 17cm (treatments 2_R and 3_S, 5_TLC) do not differ significantly from those observed at 6cm. The average difference (st. error in parenthesis) is 2.12% (±0.12%), 3.42% (±0.07%) and 2,13% (±0.13%) for treatments 2_R and 3_S, 5_TLC respectively. The fall in soil moisture for 2_R treatment at the second half of July is due to a technical problem (the relevant control valve was broken).

a





b

Fig. 36 Soil moisture for treatments 1_C and 2_R (a) and a closer look on a representative irrigation event (b)

A closer look soil moisture after on representative irrigation event (Fig. 36) reveals that soil moisture levels at 17cm do not reach the level of that at 6cm. It also appears as if water from this depth is not taken up by turfgrasses..

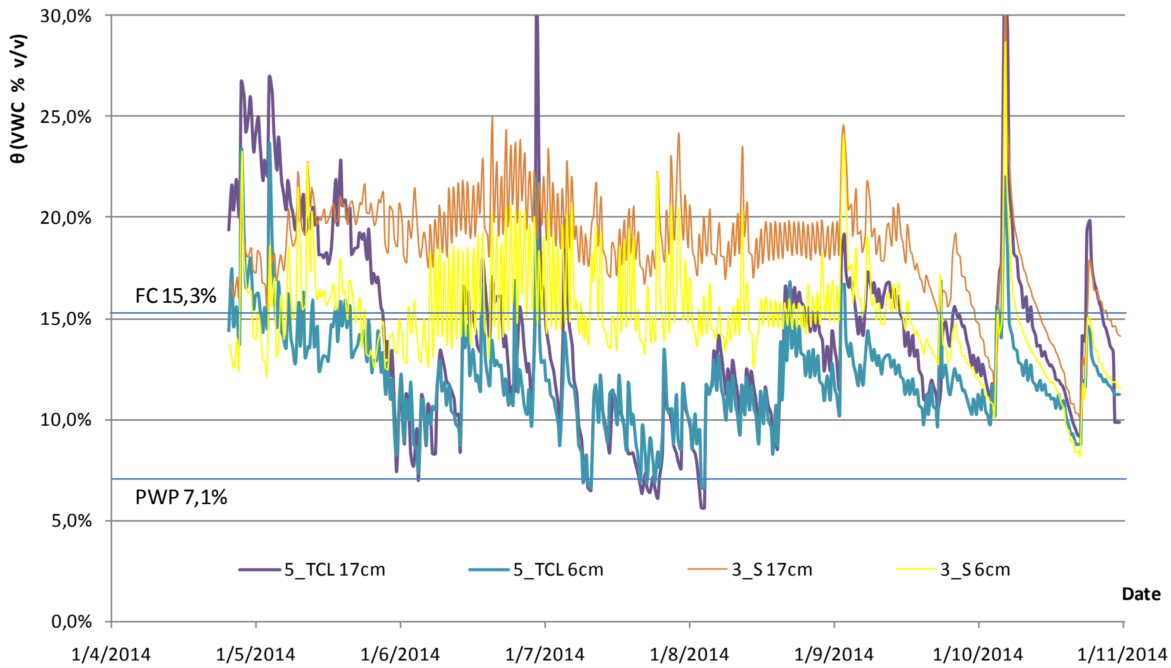


Fig. 37 Soil moisture variation for treatments 3_S and 5_TCL

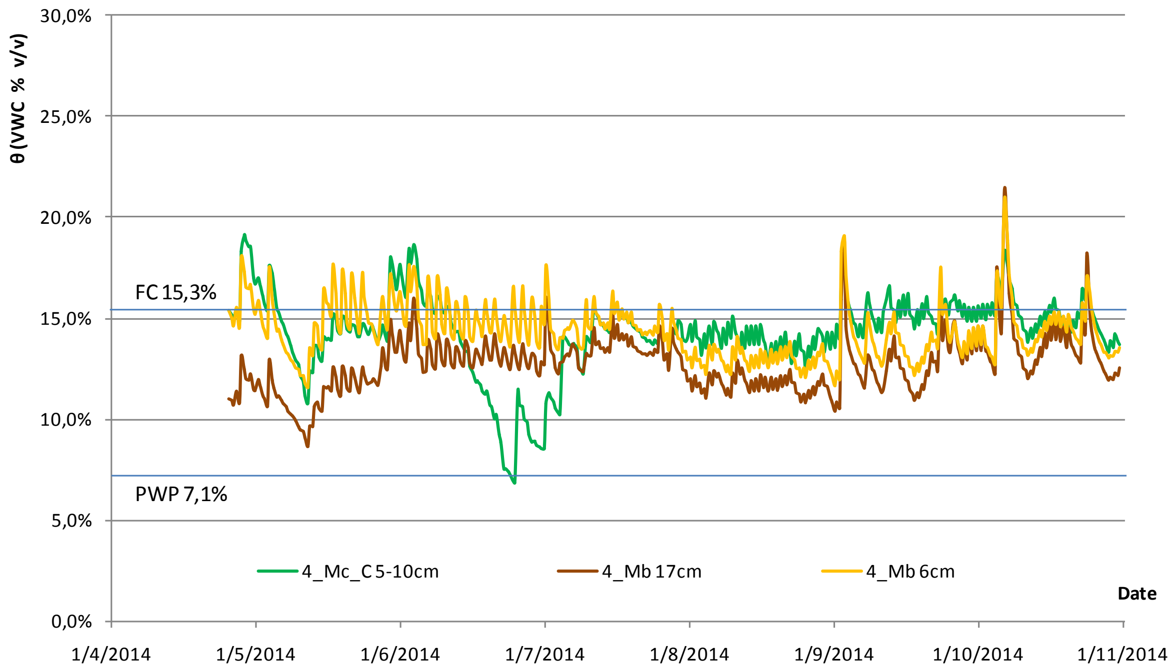


Fig. 38 Soil moisture variation for treatment 4_M

The respond of Toro PSS

Toro Precision™ Soil Sensor System performed in general very well. The intention of this sensor is to allow irrigation until near field capacity is reached, then to force a dry-down to the preset threshold. The auto calibration cycles of the sensor attempt to assign 100% to field capacity and 0% to wilt point. The selected threshold level for the present evaluation was the 50%.

The green light (irrigation is allowed) of the sensor does not come on until the moisture reading drops to below the threshold. Then the green light stays on until the moisture reading exceeds 90% (an offset selected by the manufacturer).

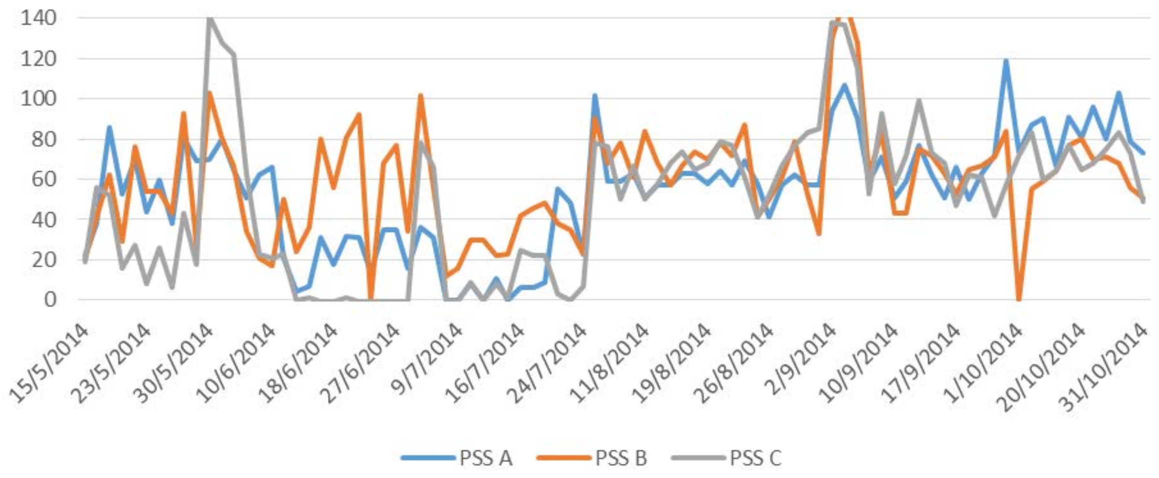


Fig. 39 Evolution of Toro PSS indications

The respond of Irritrol Climate Logic

Irritrol Climate Logic™ responded very well in our trial setting. In Fig. 40, the history values of the system are compared with the relevant values that were calculated using the Penman - Monteith approach (Allen et al., 1998) using data from the nearby meteorological station.

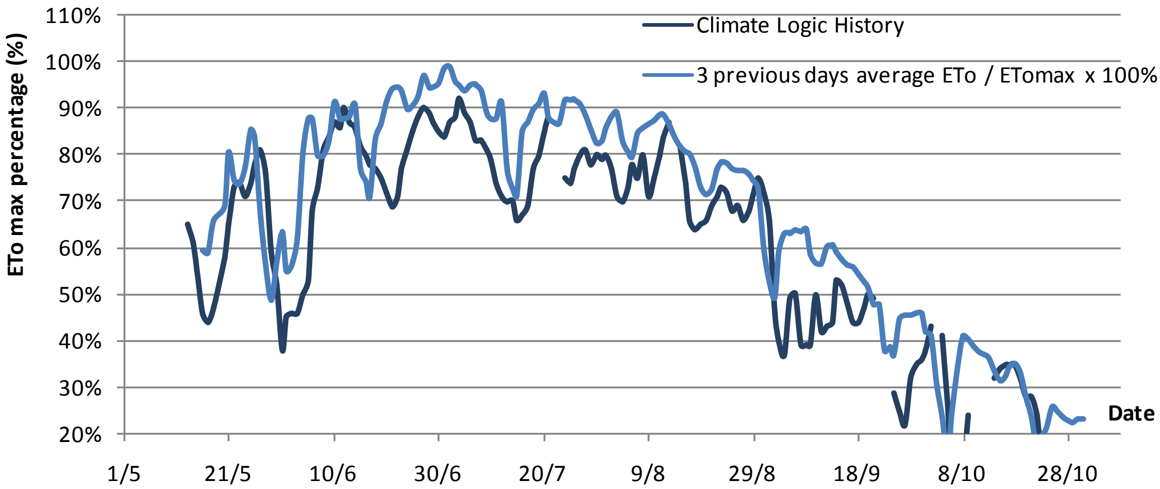


Fig. 40 Climate Logic values in comparison to measured by weather parameters ET

Irrigation water consumption

Measuring irrigation water consumption has been the most important part of this study as we investigated technologies that result in the least amount of water needed yet without any reduction in turf quality.

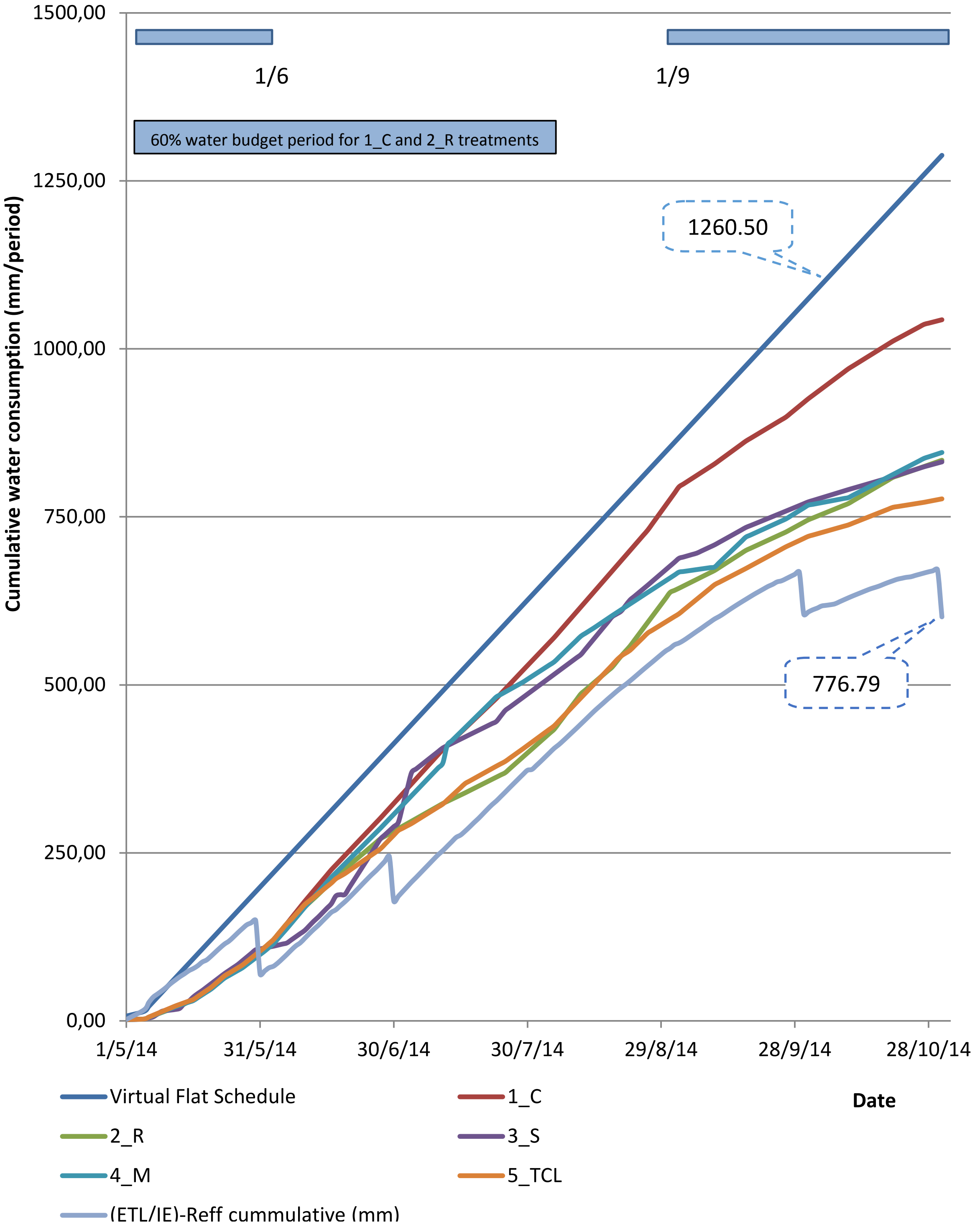


Fig. 41 Cumulative water consumption of the various treatments in regard with the irrigation needs for 2014

In Fig. 41 the cumulative water consumption of the various treatments in regard with the estimated ET_L is presented. The treatment "Virtual Flat Schedule" has not been applied in the field. It represents a hypothetic constant schedule, applied through the whole period. The 2014 calculated ET_L, is based on Penman-Monteith approach (Allen et al., 1998) along with the coefficients (ks, kd and kmc) and IE that were selected to define the theoretical schedule. The estimated 2014 effective rain (Dastane, 1978) was abstracted at the end of each month. An actual measurement of ETL (for example using a lysimetric balance would eliminate the error that probably derive from the estimation of the coefficients and the fact that they probably were not stable during the whole period). The comparison of the various treatments showed (Table 5) that at the end of the evaluation period (from 1/5 up to 31/10/2014) the cumulative consumption (mm period^{-1}) was lower for the 5_TCL system (Irritrol Climate Logic™). Results of 2_R treatment are not displayed because the systems was out of order due to a technical problem for about 15 days.

Table 4 Comparison of cumulative water consumption and estimated ET_L

Treatment	Cumulative period value (mm)	When compared to virtual flat schedule approach	When compared to estimated $(ET_L/IE)-R_{eff}$
1_C	1043.33	-19.00%	73.54%
3_S	834.29	-35.23%	38.77%
4_M	831.81	-35.42%	38.36%
5_TCL	845.83	-34.33%	40.69%
$(ET_L/IE)-R_{eff}$	776.79	-39.69%	29.21%

Turfgrass growth - Root system

Fig. 42 presents the evolution of the root growth. The statistical analysis (t-student test) revealed no statistically significantly difference between treatments 2_R, 3_S, 4_M and 5_TCL and the reference one (1_C).

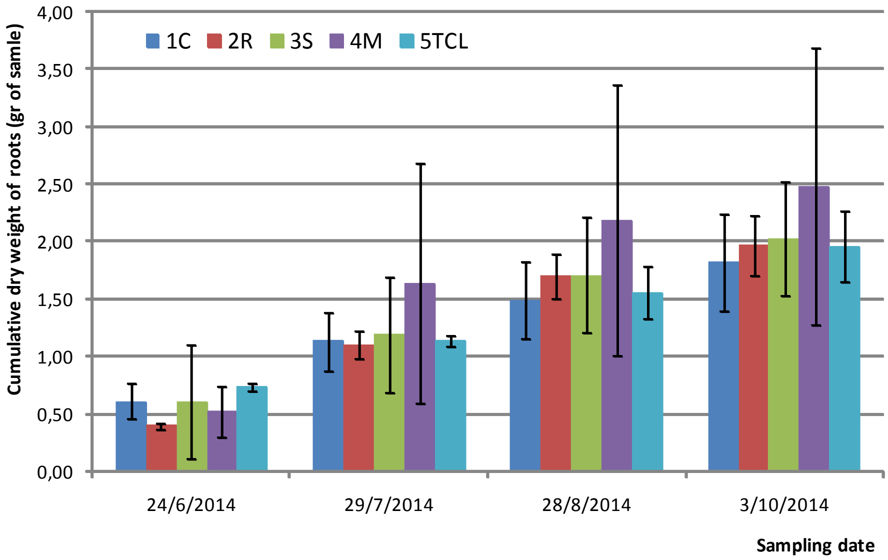


Fig. 42 Root growth evolution

Turfgrass growth

Fig. 43 presents the evolution of the aerial part growth. The statistical analysis (t-student test) revealed no statistically significantly difference between treatments 3_S, 4_M and 5_TCL and the reference one (1_C). Treatment 2_R was found to have significant differences when compared to 1_C but this could be attributed to the technical problems regarding the irrigation of 2_R during the second half of July.

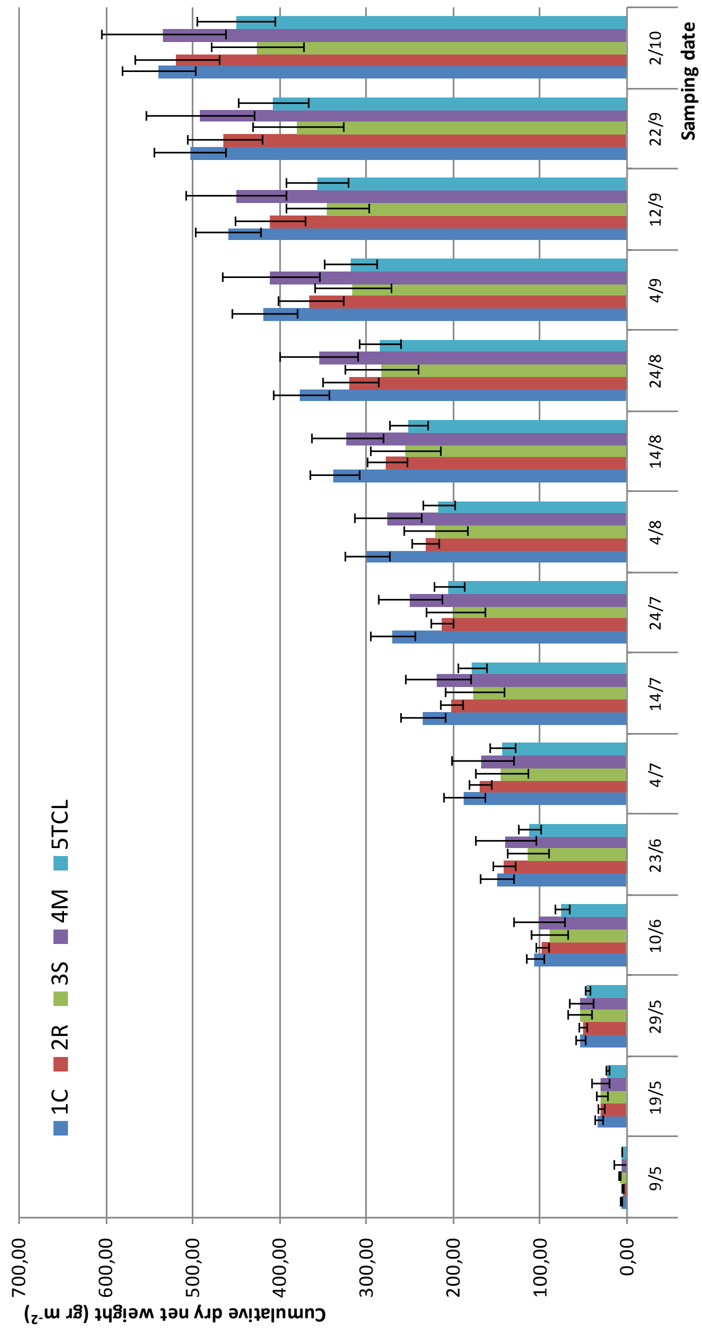


Fig. 43 Evolution of the aerial part growth

Turfgrass quality

Concerning turfgrass quality, the results for both PRI and NDVI indices are presented in Fig. 44 and Fig. 45. The restriction of irrigation for 2_R treatments (it was caused due to a technical problem) is clearly depicted in both indices and also it follows the expected timing, as PRI (which is affected by the photosynthetic activity) showed an immediate decline whereas NDVI (which is affected by the canopy density), reached the lower values few days later.

Regarding PRI, the statistical analysis (t-student test) revealed no statistical significantly difference between treatments 3_S, 4_M and 5_TCL and the reference one (1_C). No relevant analysis was performed for treatment 2_R.

Statistical analysis revealed a positive correlation between soil moisture and PRI. These finding are in accordance with those of Penuelas et al. (1994); Suarez et al. (2009) and Sarlikioti et al. (2010) who reported a decrease in PRI with time after withholding water.

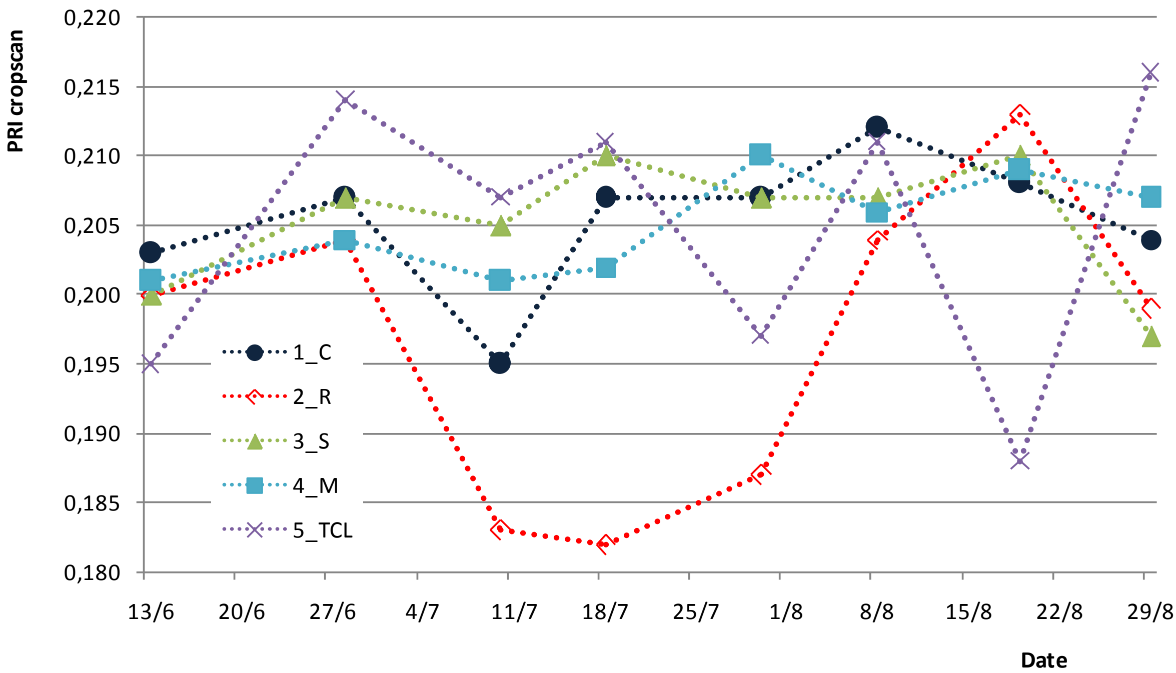


Fig. 44 PRI evolution for the various treatments (PRIcropscan = (R560 - R510) / (R560+ R510))

Regarding NDVI, the statistical analysis (t-student test) revealed no statistical significantly difference between treatments 3_S and 5_TCL and the reference (1_C). Treatment 2_M was found to have significant differences when compared to 1_C. No relevant analysis was performed for treatment 2_R.

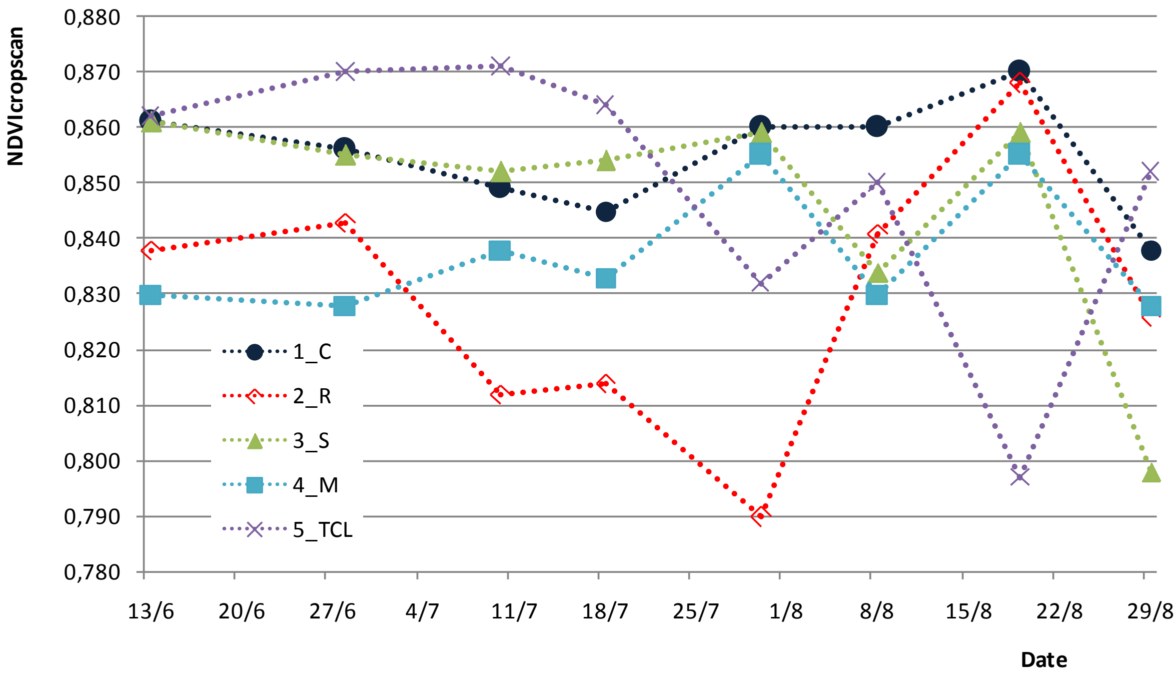


Fig. 45 NDVI for the various treatments (NDVIcropscan = (R810 - R660) / (R810+ R660))

Discussion, Conclusions and Recommendations

Irrigation management of landscape areas should be based on both science and experience. Historical climatic data, estimations of plant material water needs, soil and terrain properties, irrigation system characteristics can feed a scientifically approved method which will then provide an approximation for the frequency and duration of watering events. In each case an on-site adjustment of this theoretical irrigation schedule should also be made. Fine tuning for seasonal weather conditions could contribute significantly to the system's efficiency.

The objectives of this study were to investigate the water conservation potential of various irrigation scheduling approaches with and without the use of special sensors and to develop relevant practical recommendations to irrigation managers and home owners.

The following treatments were applied to tall fescue, a cool-season turfgrass, which is the most commonly used lawn grass in North and Western Greece:

- 1_C Control: irrigation controller using water budget periods (reference treatment)
- 2_R Rain: irrigation controller using water budget periods + rain sensor
- 3_S Solar: irrigation control using solar energy (as measured by a pyranometer) integration for continuous calculation of frequency
- 4_M SoilMoisture: irrigation controller connected to soil moisture sensor
- 5_TCL: irrigation controller connected to Evapotranspiration (ET) sensor + rain sensor

A comparison of the various treatments indicated that for the irrigation period of 2014 (from 1/5 up to 31/10/2014), the 3 smart irrigation systems, namely Irritrol Climate Logic™ (treatment 5_TCL), Toro Precision™ Soil Sensor (treatment 4_M) and the TEIEP solar radiation system (treatment 3_S), provided between 35 and 40% savings when compared to a typical theoretically calculated flat irrigation schedule. The latest is the best practice that local managers and homeowners apply.

The results of the rain sensor treatment (2_R) are not compared to the others as the system was off for about 15 days due to a technical problem. If for that period we assume that the system consumed the same amount of water as the 1_C reference treatment, then the savings from a rain sensor are estimated to be at least 25%.

Even the simple Water Budget approach (treatment 1_C) provided 20%water savings.

The considerable savings for treatments 3_S and 5_TCL were not accompanied by any decline in growth or quality of the turfgrass. Treatment 4_M showed no difference regarding growth and just a small difference regarding leaf area index when compared to the reference treatment (1_C).

A very interesting result was the quick identification of the irrigation problem in treatment 2_R by the PRI. It is reasonable to think that as a typical system sums the solar energy that reaches the pyranometer in order to trigger irrigation events it irrigates independently of the condition of the cultivation. Probably a system could do something similar -but taking account of the condition of the cultivation- by using an index based on reflectance from the canopy. Also a system like this could produce alarm signals in case of problem detection.

This report closes with the wish for a widespread of efficient scheduling techniques, sensors and smart controllers which will lead to significant conservation of water.

A very recent information for irrigation scheduling reveals very interesting facts regarding how this task is done

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%).

Linkage with other IRMA Deliverables

The TEIEP solar radiation system (treatment 3_S) is already developed with the function to use solar radiation values that are provided by the IRMA_SYSTEM (IRMA WP5, Actions 5.3, 5.4 and 5.5). This will eliminate the need for an individual pyranometer for each installation.

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