

AN EARTH OBSERVATION ASSISTED TOOL FOR IRRIGATION WATER MANAGEMENT

Filiz BARBAROS¹, Ali GÜL² & Nilgün HARMANCIOĞLU³

(1) Dokuz Eylül University, Water Resources Management & Research Center – SUMER Tınaztepe Campus, Buca 35160 İzmir - TURKEY, email: filiz.barbaros@deu.edu.tr

(2) Dokuz Eylül University, Water Resources Management & Research Center – SUMER Tınaztepe Campus, Buca 35160 İzmir - TURKEY, email: ali.gul@deu.edu.tr

(3) Dokuz Eylül University, Water Resources Management & Research Center – SUMER Tınaztepe Campus, Buca 35160 İzmir - TURKEY, email: nilgun.harmancioglu@deu.edu.tr

ABSTRACT

Water is a critical issue worldwide and water conflicts are arising in many regions, with available resources diminishing in quantity and quality and the range of uses in competing sectors increasing. Periodic droughts and floods exacerbate conflicts and reveal the increasing vulnerability of water uses. Water for food production, and hence water for irrigation, represents by far the largest share among all uses, while water demand is still growing with increasing population, especially in developing countries.

This paper focuses on newly developed technologies for irrigation water management within a research and technological development project funded by the European Commission's 6th Framework Programme, entitled PLEIADeS (Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision-Support). PLEIADeS addresses the efficient and sustainable use of water for food production in water-scarce environments. It aims at improving the technical, environmental and economic performance of irrigation schemes by means of a range of measures. A key feature of the project is a set of systems and services integrated with the comprehensive space-time coverage of Earth observation (EO) data and the interactive networking/connecting capabilities of Information and Communication Technologies (ICT). It is also the basis for technical and social learning that enables farmers to act responsibly by fine-tuning their on-farm irrigation management in accordance with the river-basin water status and management decisions.

The project has benchmarked the technical, environmental, and economic performance of irrigation systems in the pilot river-basins, conducted trial campaigns with EO- and ICT-assisted products in a participatory evaluation with stakeholders, and assessed the effect of the new tools on water productivity and performance of the pilot irrigation systems.

In the presented study, the tool introduced and tested by PLEIADeS Project is briefly explained in terms of the Turkish case study irrigation system, while discussing the capabilities of the new technique for irrigation water management and its role in improving the performance of irrigation schemes along with measures that consider the economic, environmental, technical, social, and political dimensions of water management.

1 INTRODUCTION

In recent years, several problems have emerged due to water scarcity and deterioration in water quality. Accordingly, accurate information of water consumption has been a critical need on irrigation water management, and estimation of the required quantity of water for irrigational use has been increasingly important especially in cases where there is significant competition between water sectors.

Irrigation management under water scarcity and water pollution has become more important and complex. Water scarcity affects the quantity of the resource available whereas the pollution affects the quality of the water available for irrigation. Environmentally, socially and economically sustainable use of water is a priority for agriculture especially in water scarce and polluted basins. There are different causes of water scarcity, which directly impose varying stresses on irrigation management, such as aridity, drought, desertification and water shortage (Pereira et al., 2002). These can be further classified into two with respect to their evolution mechanisms, i.e., nature-made and man-made.

The concept of irrigation modernization has evolved over the years from the mere introduction of new technical infrastructure and equipment towards a more holistic concept including measures to optimize water application. Such a system now includes also tools to generate information on most efficient water use and mechanisms to transmit this information to farmers (Osann, 2010). To this end, several methods have been developed recently to execute the amount of water demand on the basis of each crop pattern.

The System of Participatory Information, Decision support, and Expert knowledge for irrigation and River basin water management (SPIDER) has been defined as one of these methods in scope of a research and technological development project funded by the European Commission's 6th Framework Programme, entitled PLEIADeS (Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision-Support). PLEIADeS addresses the efficient and sustainable use of water for food production in water-scarce environments. This system is based on GIS and enables the users to have an idea of water consumption of the crops by determining the consumption through satellite images (PLEIADeS, 2009).

2 THE ROLE OF EARTH OBSERVATION IN IRRIGATION MANAGEMENT AND THE SPIDER SYSTEM

Earth Observation (EO) in general terms is the gathering of information about planet Earth's physical, chemical and biological systems. It is used to monitor and assess the status of, and changes in, the natural environment and the built environment. EO provides an objective evaluation of crop water demand, and the analytical outputs can be used at different decision levels (from the farmers to the river basin authorities) to promote a more efficient use of water resources in agriculture. A rational management of water resources for irrigation requires information characterized by high temporal and spatial variability, which cannot be monitored with traditional field inspections. EO is a mature technology, ready for being transferred to operational applications in agricultural water management. Detailed data on crop development and irrigation needs are timely distributed to final users by means of modern Information and

Communication Technologies. In this study, which is performed as a part of the European 6th Framework Project PLEIADeS, a portfolio of EO-based products has been set-up and the methodologies for their retrieval have been defined, starting from past experiences and scientific knowledge available among the partners in the project consortium. F.A.O. (Food and Agriculture Organization) methodology has been adopted as the standard procedure for computing crop water requirements from EO-based products.

SPIDER contributes significantly to facilitating participatory process and collaboration of all stakeholders and to enhancing transparency in irrigation water management. SPIDER is a web-based GIS (S. Dragicevic, 2004) that doesn't need to install any software in the client PCs. It has been developed based on those new technologies as a centralized data server where different users can upload different kinds of layers (vector, raster, alphanumerical, etc) and work together with them in a participatory and collaborative environment, as a support for the academic and research groups, as well as for the different stakeholder levels implicated on the water management issue (Fig. 1).

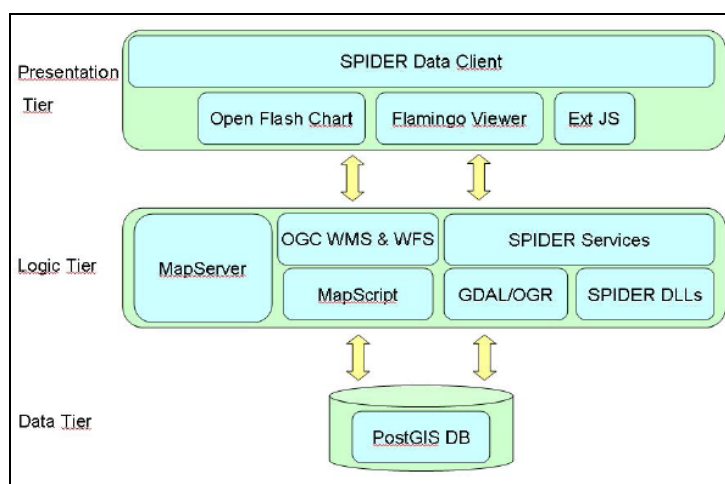


Figure 1. General components of the SPIDER system.

SPIDER basically offers the following functionalities to decision-makers and its beneficiaries (SPIDER, 2007):

1. *Managing Users:* SPIDER gives the opportunity of managing different levels of users and groups with restringed access to information by content and by spatial boundaries, so that the manager is able to give each user just access to the information it has rights to.
2. *Managing Environments:* For each group defined in the SPIDER system, the manager is able to design a specific environment defining the information that must appear for each group at the start and also defining the rights to access for that group.
3. *Loading Information:* In SPIDER, the defined users are able to flexibly upload digital information layers of their site of interest in different file formats.

One of the basic pillars of this software is the use of EO technologies to cover large areas with a few images, and supporting different resolution satellites provides a high potential toolkit for different levels of water management (river basin, governmental and irrigation level stakeholders). The temporal evolution is visualized in interactive charts that also allow accumulation along the time axis. This kind of layers consists of a dynamic mosaic of images with a spatial and a temporal component, covering different areas on different dates, making available the temporal raster-based analysis of data.

The two most important ways SPIDER helps users can be resumed as (a) in the river basin level, the system offers a wide land coverage visualization and a data exploiting tool for monitoring historical changes based on the land cover use maps and EO data, as well as for planning water distribution plans for following campaigns; and (b) in the irrigation level as a real-time process, farmers can follow the evolution of their different crops knowing in each moment the amount of water they need and detecting problems in irrigation systems, crop diseases, etc.

3 STUDY AREA: GEDİZ RIVER BASIN & MENEMEN LEFT-BANK IRRIGATION

The study area, Gediz River Basin, is located in western Anatolia in the Aegean region, neighboring the city of Izmir. It ranks as the second largest basin in the region with its drainage area of 18 000 km² (2.3% of the total surface area of Turkey) (Fig. 2). The basin holds a total population of 1 700 000. Within the context of irrigated agriculture in the basin, 13 irrigation associations perform operations and maintenance duties over a territorial extension of about 110 000 ha. There are; however, serious institutional, legal, social and economic drawbacks which enhance water allocation and water pollution problems. Water scarcity contributes more to these problems and is basically due to competition for water among various uses and water pollution. It is not, however, a mature basin, in the sense that the institutional set-up is not yet fully developed. Both surface and groundwater use are largely unregulated, and groundwater extraction is growing rapidly in response to urban and industrial demand.



Figure 2. Location of the study area: Gediz River Basin.

The largest user of water has been irrigated agriculture, originally deriving from small run-of-the-river diversions from the Gediz and its tributaries dating back some 3000 years. Since 1945, the developments of large-scale systems and groundwater exploitation have transformed irrigated agriculture. Adala and Emiralem regulators, the latter of which diverts water to the Menemen left-bank irrigation, are considered within major structural improvements serving mainly for irrigation water supply in the basin. Drinkable water usually comes from deep wells because of groundwater pollution. Today, Menemen plain is closed to further groundwater extraction and irrigation use of groundwater is largely static or declining as less-water intensive crops replace cotton.

All these quantitative, qualitative and managerial problems address the need for setting up a generic framework for irrigation water management and performing feasible assessments of crop water demand especially if regular in-situ measurements become available and EO-assisted technologies find place extensively in assessments. Another pillar of such a framework is the process of participation to tackle the challenges of high variability of rainfall patterns (increasing due to climate change), the conservative nature of farmers in adapting new technologies, and the lack of proper control and recording within the current irrigation system on who uses how much water.

4 APPLICATION

4.1 Selection of Satellite/Sensor for Images and Basic Image Processing

The first step in any EO-based operation is the selection of a satellite/sensor combination that satisfies the temporal, spectral, radiometric and spatial resolution requirement for a given application and that is convenient for use in agricultural applications. The challenge here is to find a reliable methodology to inter-calibrate the observations from different sensors at different observation scales in different platforms. In this current study, Landsat5-TM (thematic mapper) images were executed for performing assessments on irrigation management efficiency (Fig. 3(a)). As the original images received from the data provider were either not geo-referenced or lacking correct geometric positioning, they were first processed for geometric correction (or geo-referencing) by using a set of selected ground control points with known coordinates and with sufficient coverage of the entire image. This operation was performed on separate GIS software, IDRISI-Taiga, by using its built-in resampling techniques. The resampling was based on the approach of Nearest Neighborhood in which the geometrically closest values are assigned to the locations of questioned values (Fig. 3(b)). These geometrically-corrected images from different image acquisition dates were then transformed into the UTM-WGS84 projection that was preferred as a common working & display platform in the study (Fig. 3(c)).

Afterwards, atmospheric correction was performed on the set of images to eliminate or compensate atmospheric distortion in radiometric signal. In doing so, relative atmospheric correction method was used to normalize the signal obtained in a satellite time series to the signal of one single of a cluster of images considered as the reference. Each single band was normalized respect to the reference (Schroeder et al., 2006) (Fig. 3(d)). This operation was again performed on the IDRISI-Taiga software.

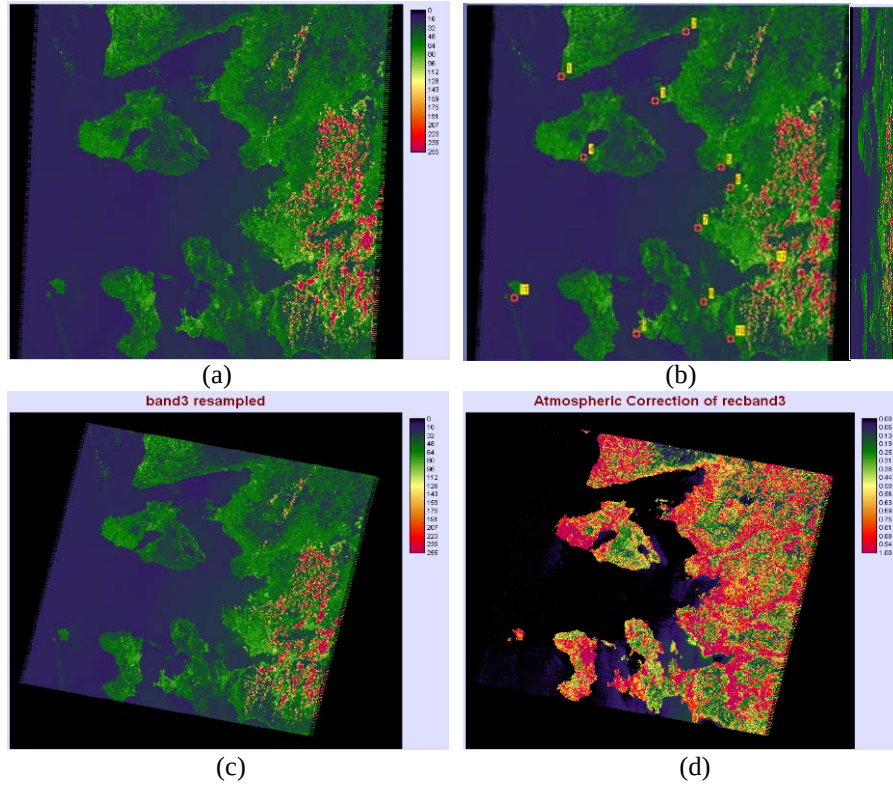


Figure 3. (a) Raw Landsat5-TM image, (b) Ground control points used for geometric correction, (c) Projected image, (d) Image after atmospheric correction.

4.2 Generation of RGB colour composites and NDVI images

RGB (red-green-blue) colour composite is a helpful product in the application of remote sensing techniques. RGB colour composite images were generated in the study from geometrically-referenced and atmospherically-corrected Landsat5-TM images based on the combination of ShortWave Infrared band (SWIR, Band 5) in the red channel, Near InfraRed band (NIR, Band 4) in the green channel, and Red band (Band 3) in the blue channel to identify natural surfaces, soil, vegetation, etc.

In order to determine the density of green on a patch of land, the distinct colours (wavelengths) of visible and near-infrared sunlight reflected by the plants need to be observed as well. The Normalized Difference Vegetation Index (NDVI) is a simple numerical indicator that can be used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not. The principle here is that chlorophyll causes considerable absorption of incoming sunlight, whereas a plant's spongy mesophyll leaf structure creates considerable reflectance (Tucker 1979, Jackson et al.1983, Tucker et al. 1991). Thus, NDVI computation employs a difference formula to quantify the density of plant growth on the Earth, and the equation is in the form of near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. In corresponding terms of Landsat5-TM bands the equation is as follows (Fig. 4 (a) & (b)):

$$\text{NDVI} = (\text{Band 4} - \text{Band 3}) / (\text{Band 4} + \text{Band 3})$$

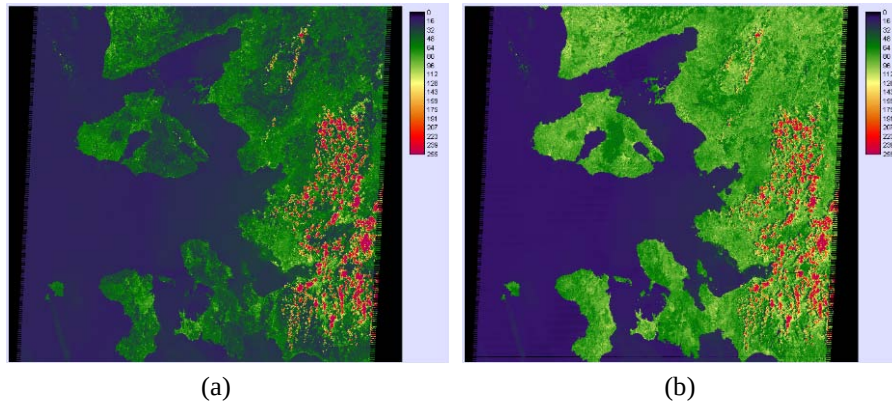


Figure 4. (a) Landsat5TM Band 3, (b) Landsat 5TM Band 4.

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation (i.e. bare soil) and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. In the current study, NDVI maps ranging between June, 05th and August, 24th, 2008 were generated to be used in computation of the EO-derived products of interest in later stages of the project (Fig. 5).

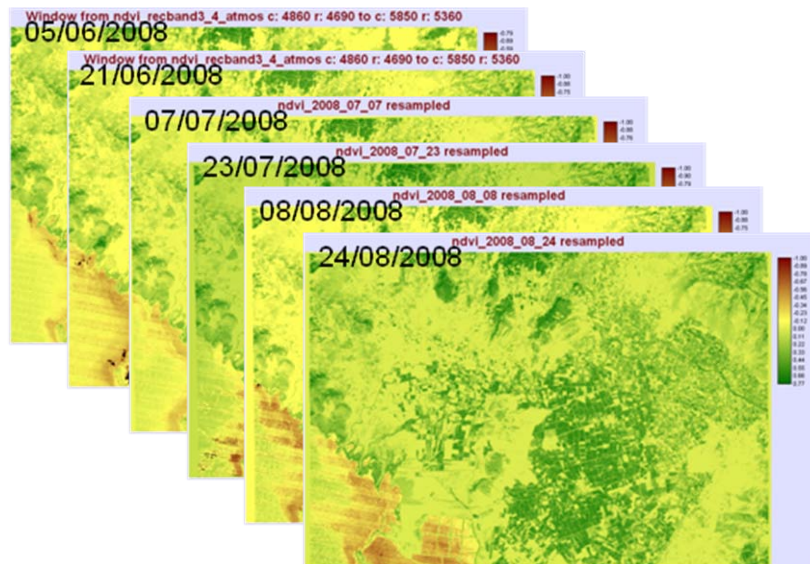


Figure 5. NDVI maps from different dates during the irrigation campaign period.

4.3 Generation of EO-derived products: Assessment of crop coefficient

One fundamental element of performing ex-post evaluation on recent irrigation applications in a field or agglomeration of fields in agricultural land, and collecting basic indications on how to diversify practices for an efficient irrigation management is the crop evapotranspiration, ET. The computation of ET is based on two other relevant factors, reference evapotranspiration (also called reference crop evapotranspiration), ET_o , and basal crop coefficient, K_{cb} . ET_o is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m (4.72 in), a fixed surface resistance of 70 sec m⁻¹ (70 sec 3.2ft⁻¹) and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground. The grass crop is generally defined as the reference crop in the reference evapotranspiration definition, and this crop is assumed to be free of water stress and diseases (Irmak & Haman, 2003). ET_o for grass can be obtained from its satellite-based or ground-measured rates in grass planting areas throughout the world. K_{cb} , on the other hand, is the ratio of the unstressed crop transpiration over the reference evapotranspiration (Allen et al., 1998), thus can be used in other way around to estimate ET based on the known values of ET_o as performed in this current study. The general analytical framework of activities to obtain ET values is presented in Fig. 6.

In the study, NDVI values were processed through an analytical approach and used together with other supplementary factors (i.e. vegetation coverage, leaf area index (LAI), surface albedo coefficient, and canopy height) finally to estimate the applicable rates of K_{cb} . All these analyses were conducted for four pilot parcels including cultivation of three different crop products; vineyard, cotton and maize (Fig. 7).

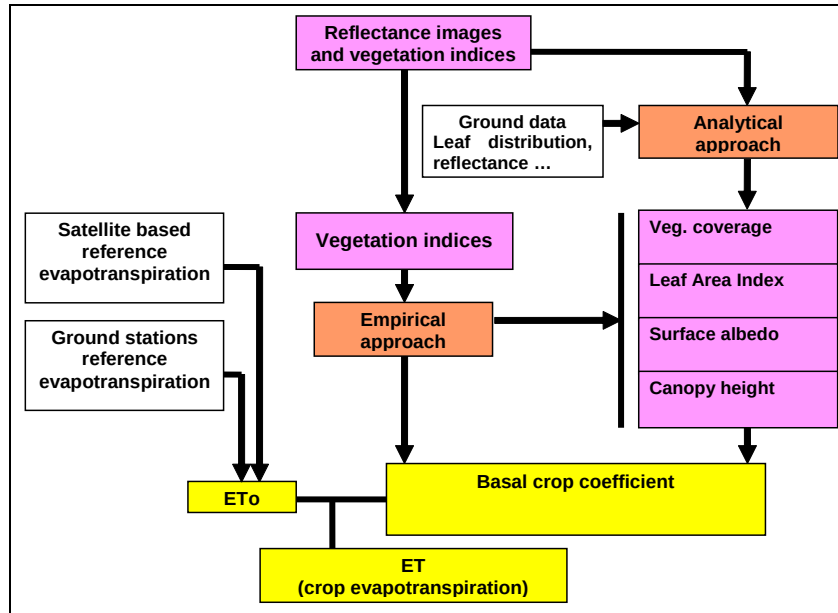


Figure 6. General analytical framework for ET computation.

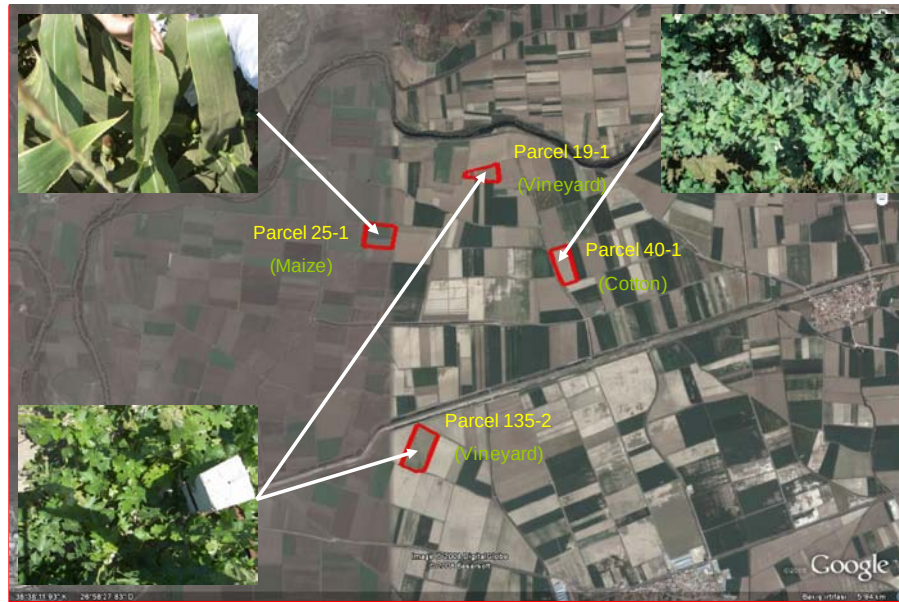


Figure 7. Locations of pilot parcels and corresponding crop products.

5 RESULTS & DISCUSSION

From the NDVI maps generated for the entire study area that is slightly wider than the coverage of the pilot parcels, NDVI averages inside each parcel were computed for all dates available in the time tile. Fig. 8 shows the average NDVI values for different time instants to visualize its change in time and have some clues about the evolution of corresponding crop products (i.e. vineyard, maize and cotton).

In the SPIDER platform, the NDVI averages for the pilot parcels were further processed and combined with other supplementary data (LAI, surface albedo, etc.) to compute basal crop coefficients that would be required for the final computation of crop evapotranspirations (Fig. 9).

The basal crop coefficients were finally multiplied by the reference evapotranspiration, again by using the built-in capabilities of SPIDER, and finally crop evapotranspirations that correspond to the crop type in each of the pilot parcels were obtained and displayed in the SPIDER interface as partial duration time series as shown in Fig. 10.

The evolution of crop evapotranspirations in all four pilot parcels provided a good indication for exploring the existence of any parallel behaviour between the water requirements associated with the crop growth and the amounts of irrigation water supplied to the fields. Yet, a number of improper irrigation applications were detected in certain time slots due to both the shortcomings in the water availability in the irrigation campaign periods and the lack of required knowledge on how to diversify water supply in crisis periods or the lack of full public/administrative awareness that is normally expected to serve for a near-efficient irrigation water management.

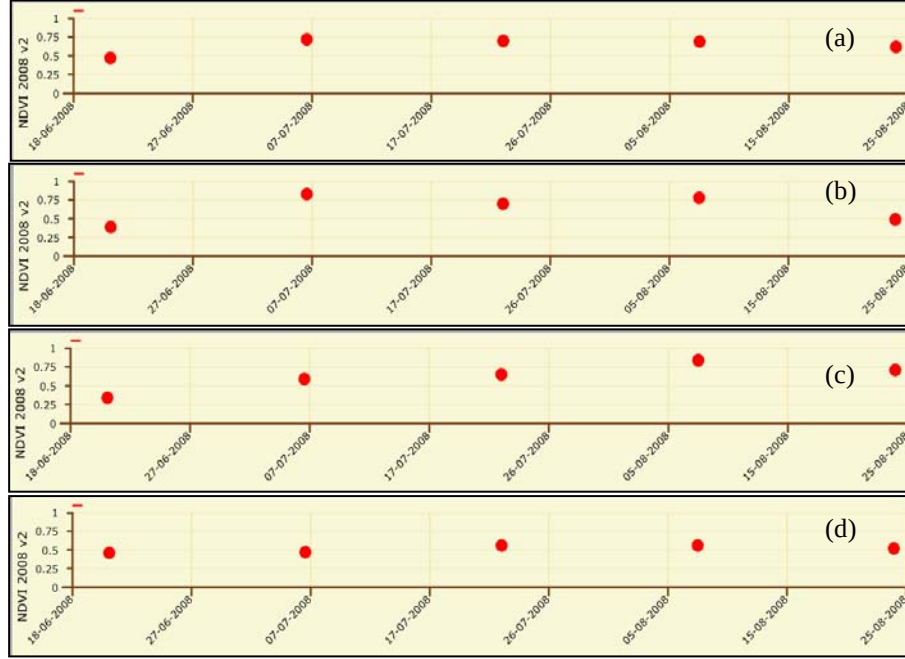


Figure 8. NDVI time series for parcels (a) 19-1, (b) 25-1, (c) 40-1 & (d) 135-2.

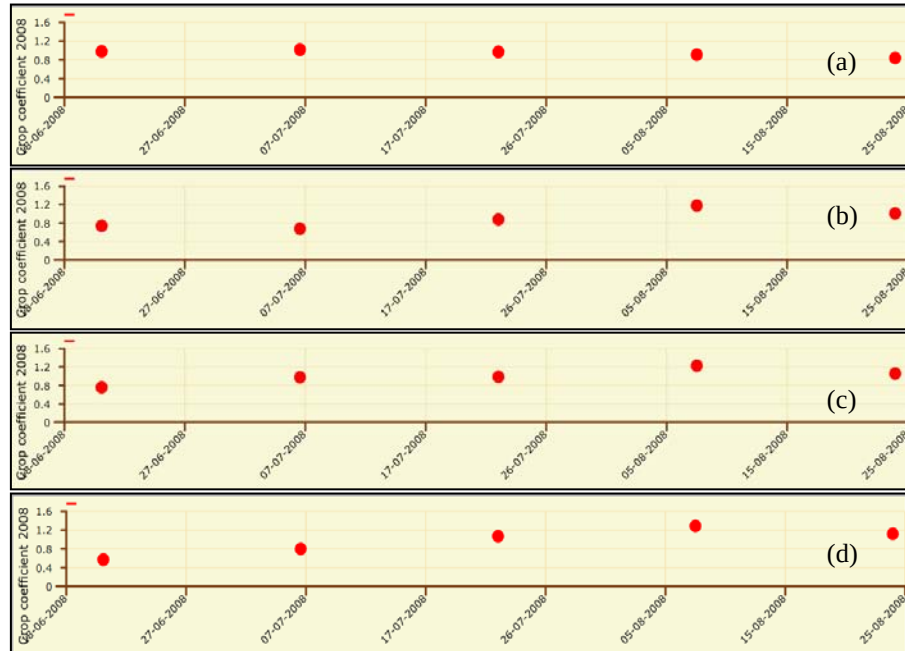


Figure 9. Crop coefficient time series for parcels (a) 19-1, (b) 25-1, (c) 40-1 & (d) 135-2.



Figure 10. Crop evapotranspiration time series for parcels (a) 19-1, (b) 25-1, (c) 40-1 & (d) 135-2.

For farmers and irrigation scheme water managers, it should, however, be acknowledged that SPIDER generates weekly or bi-weekly irrigation scheduling information products from a virtual constellation of high-resolution EO satellites and delivers them to farmers in near-real-time using leading-edge on-line analysis and visualization tools. It is supported by a methodology package to derive crop coefficients and further advanced parameters from EO satellite images in an operational processing chain.

6 CONCLUSIONS

Spatial patterns and temporal evolutions of remotely sensed ET are valuable when used for irrigation scheme performance assessment. Combining Earth Observation (EO) Technologies with web-based GIS offers an environment for exploring and analyzing spatial temporal data and monitoring evolution of crops and natural vegetation, as well as estimating water consumption in wide regions of land. At this point, SPIDER comes forward as an innovative system composed of a number of built-in functionalities and system tools designed to this end.

Beyond its analytical capabilities as a stand-alone software application, SPIDER can connect with external Web Map Services, offering the option of comparing and combining the data from SPIDER with other official and non-official data available in the network based on Open Geographical Consortium standards, which are widely used, especially in Europe as a requirement of initiatives like the European Directive INSPIRE. It is also important to mention the benefits that SPIDER offers to the

scientific environment for publishing and sharing research results, and for promoting the collaboration between the different hierarchy levels in irrigation water management.

Another significant conclusion drawn from the overall operations performed in this study is that traditional data production processes need some adaptation to the new technologies and standards in most cases. It is necessary to be ready for the new revolution that the web is going to witness, becoming the most important and open data network.

The launch and rapid improvement of mobile technologies are expected to potentially provide the future platform for accessing those data from the field. Although these kinds of innovative approaches were standing as utopia in the past, it is much more probable today to integrate such technologies into the efforts of efficient and sustainable irrigation management for improving irrigation water use and securing irrigation water supply especially in cases of water scarcity arising from either quantitative or qualitative matters. However, the success of these new approaches depend very much on the efforts to raise awareness of the general public on the importance of a responsible use of water and thus to promote a participative framework for a bottom-up irrigation water management.

Acknowledgments. As this paper was compiled from the outcomes of the regional case-study performed under the EU 6th FP Project PLEIADeS, the authors thank to the colleagues from the project consortium involved in the SPIDER development.

REFERENCES

- Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop requirements. *Irrigation and Drainage Paper* No. 56, FAO, Rome, Italy.
- Folhes, M.T., Renno C.D., Soares J.V. (2009). Remote sensing for irrigation water management in the semi-arid Northeast of Brazil, *Agricultural Water Management* (96), Elsevier 1398-1408.
- Irmak, S. & Haman, D. Z. (2003). Evapotranspiration: Potential or Reference?, *Agricultural and Biological Engineering Department Series*, ABE 343, University of Florida.
- Jackson, R.D., P.N. Slater, and P.J. Pinter, 1983. Discrimination of growth and water stress in wheat by various vegetation indices through clear and turbid atmospheres. *Remote Sensing of the Environment*, v. 15, p.187-208.
- Osann, A. (2010). EU 6th FP Project "Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision-Support" Final Activity Report,
- Pereira, L. S., Oweis T. & Zairi, A. (2002). Irrigation management under water scarcity, *Agricultural Water Management* (57), Elsevier 175-206.
- PLEIADeS (2009). EU 6th FP Project "Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision-Support" official web page, www.pleiades.es, (date accessed: 25.04.2011).
- Schroeder, T. A., Cohen, W. B., Song, C., Canty, M. J. & Yang, Z. (2006). Radiometric correction of multi-temporal Landsat data for characterization of early successional forest patterns in western Oregon. *Remote Sensing of Environment*, 103: 16-26.
- SPIDER (2007). "The System of Participatory Information, Decision support, and Expert knowledge for irrigation and River basin water management - SPIDER" conceptual document.
- Tucker, C.J. (1979) 'Red and Photographic Infrared Linear Combinations for Monitoring Vegetation', *Remote Sensing of Environment*, 8(2),127-150
- Tucker, C. J., W. W. Newcomb, S. O. Los, and S. D. Prince, 1991. Mean and inter-year variation of growing-season normalized difference vegetation index for the Sahel 1981-1989. *International Journal of Remote Sensing*, v. 12, p.1113-1115.