Operational Space-Assisted Irrigation Advisory Services: Overview Of And Lessons Learned From The Project DEMETER

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Abstract. The project DEMETER (DEMonstration of Earth observation TEchnologies in Routine irrigation advisory services) was dedicated to assessing and demonstrating improvements introduced by Earth observation (EO) and Information and Communication Technologies (ICT) in farm and Irrigation Advisory Service (IAS) day-to-day operations. The DEMETER concept of near-real-time delivery of EO-based irrigation scheduling information to IAS and farmers has proven to be valid. The operationality of the space segment was demonstrated for Landsat 5-TM in the Barrax pilot zone during the 2004 and 2005 irrigation campaigns. Extra-fast image delivery and quality controlled operational processing make the EO-based crop coefficient maps available at the same speed and quality as ground-based data (point samples), while significantly extending the spatial coverage and reducing service cost. Leading-edge online analysis and visualization tools provide easy, intuitive access to the information and personalized service to users. First feedback of users at IAS and farmer level is encouraging. The paper gives an overview of the project and its main achievements.

Keywords: Irrigation Advisory Service, remote sensing, information and communication technology, on-line analysis.
PACS: 92.40Xx, 92.40Je.

INTRODUCTION

Irrigated agriculture is the main consumer of freshwater in large parts of the world. Therefore, it is the key strategic focus for efficient water use. Accordingly, 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. Irrigation Advisory Services (IAS) are ideal management

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instruments for this purpose and they are gradually adopting this extended role (Martín de Santa Olalla et al., 2004).

New tools are needed to support this process. Current IAS are normally not able to cover each farm holding in extended areas at regular short time intervals. Earth observation (EO), in combination with Geographical Information Systems (GIS), is naturally destined to fill such a gap. In parallel, last-generation Information and Communication Technologies (ICT) open vast possibilities to transmit spatialized information to users in a personalized way using internet and mobile phones.

The project DEMETER (DEMonstration of Earth observation TEchnologies in Routine irrigation advisory services) was dedicated to assessing and demonstrating improvements introduced by EO and ICT in farm and IAS day-to-day operations (see Calera et al. 2005 for a detailed description). Case studies were performed in pilot areas in Spain (this paper; González-Piqueras et al.; Montoro et al., this volume), Portugal (Perdigão et al.; Café et al., this volume), and Italy (d'Urso et al., this volume). The transferability to further areas was investigated for North Portugal and Greece (Baptista et al.; Domenikiotis et al., this volume)

The basic product obtained in DEMETER from a sequence of (e.g., weekly) satellite images is maps of crop coefficient K_c along with its temporal evolution at a given place. Crop coefficient is also the basic parameter used by traditional IAS for the estimation of crop evapotranspiration (following FAO methodology, Allen et al. 1998). Therefore, the EO-derived K_c maps can be introduced directly into the routine IAS information generation flow for irrigation scheduling. Crossing (multiplying pixel by pixel) the K_c map with a map of reference evapotranspiration ET_0 (obtained from agrometeorological stations or by any other means) gives directly a map of crop evapotranspiration, which is then used to determine crop water requirements.

The methodology to derive K_c maps from multispectral satellite images has been amply validated with multi-annual data (2003-2005) from three DEMETER pilot zones in Spain (Cuesta et al., 2005), Portugal (Perdigão et al., this volume), and Italy (d'Urso et al., this volume). A comparison has been performed between all approaches utilized to obtain K_c, including methodologies based on surface energy balance approach like METRIC and MSSEBS (Rubio et al., this volume). Advanced parameters were studied by Colin et al. (2 papers, this volume) and Menenti et al. (this volume). A brief summary of the evaluation of the technical quality of products will be given below in the second part of this paper.

The key feature of the new Space-assisted IAS (e-SAIAS) is the operational generation of irrigation scheduling information products and their delivery to farmers in near-real-time using leading-edge online analysis and visualization tools. We describe in the following the procedures, products, success achieved and lessons learned in the process.

OPERATIONAL SPACE-ASSISTED IRRIGATION SCHEDULING

The operational routine consists of three steps: the near-real-time satellite image reception; immediate and fast basic processing of satellite data, inter-satellite calibration, product elaboration and integration into the IT system; and immediate delivery to end users (IAS and farmers). We describe here the experience from the Barrax pilot zone, with occasional referrals to other pilot zones.

In order to comply with the temporal requirement of irrigation scheduling the operational space-assisted irrigation scheduling must provide a time series of weekly images during the entire growing season of crops in a given area (4-8 months). Maps of crop water requirements are derived from each image and introduced directly in existing routine irrigation advisory operations, which are based on standards recommended by FAO. The EO-derived information replaces and complements data previously obtained by resource-intensive field work or averaged tables. Introduced into a GIS, it opens the access to the spatial dimension and thus, a more accurate prediction of irrigation water needs of individual fields and personalized service to farmers.

Near-Real-Time Reception Of Satellite Images

The operational procedure is based on a virtual constellation of all available high-resolution EO satellites, to achieve the required space-time resolution (10-30 m, weekly). The virtual constellation is tied together by means of a novel inter-satellite cross-calibration procedure (Martínez et al. 2005). Due to its excellent operational availability and low cost, and in spite of recent technical problems of both Landsat 5 and Landsat 7, Landsat is the backbone of this virtual constellation. The other high-resolution satellites (IRS, Spot, Terra-Aster, ALI) are less operational and/or significantly more expensive. Therefore, their role is mainly to fill gaps in the time series.

During the 2004 and 2005 irrigation campaigns, upon special arrangement with Eurimage for rush-delivery, Landsat 5-TM images were available on their server several hours after image acquisition time, ready to be downloaded by means of FTP. For the Barrax study area, the Lansdsat 5-TM satellite acquires images at 10:30 GMT. Usually the image was available this way on the same day at 15:00 GMT.

This capability represents a major progress in Remote Sensing applications development. Along with many earlier authors, Bastiaanssen et al. (2000) stress that timeliness has been the main constraint for remote sensing farm management applications. For the Barrax area, the coverage frequency was eight days because the study zone is located in the overlap area for the 199-33 and 200-33 Landsat 5-TM paths. A total of 24 images were obtained per irrigation season (during six months of each year).

Operational Image Processing And Product Generation

Immediately following image download, the basic processing is performed according to a standardized protocol (Cuesta et al., 2005; Calera et al., 2005). Methodological steps include geometric correction, atmospheric correction, reflectances estimation, NDVI map calculation, calculation of K_c maps and further products; in addition, false color maps (RGB543: combination of thematic bands 5,4,3) are elaborated.

This operational procedure includes two points of quality control: Clouds detection and, still more relevant, an image quality control taking in account the values of maximum NDVI for completely green cover and the NDVI value for bare soil. These image quality control points allow to guarantee the reliability of the image sequence. This quality control procedure is similar to image normalization.

The operator in charge of this procedure was a non-expert on image digital analysis, to check the reproducibility of the procedure. The early morning after image reception was a typical time to finish the basic processing and product generation for the entire image.

Prototype Products For Distribution To Users

A test group of representative farmers was set up and a participatory test was performed during the irrigation campaign of 2004, in order to develop and fine-tune basic user-friendly products and evaluate its characteristics. For this purpose, the "Farmer's Report" was developed as a personalized service to farmers. Each farmer received weekly by e-mail the information about crop water requirements in the Farmer's Report, of which Figure 1 shows an example corresponding to one farm. Each Farmer's Report shows only the plots that belong to the particular farm. On the left hand side, a map of actual K_c for the current weekly period is presented together with a color combination (RGB543) image for the same area (top panel). The same information is given for the previous week (bottom panel), in order to be able to visualize changes. On the right hand side of the page, a temporal evolution of K_c for each of the different monitored plots is displayed. Finally, information about crop water requirement from actual Irrigation Advisory Service (IAS) is also displayed in a table to allow for comparison with satellite derived crop water requirements (e-SAIAS).

A lesson learned from users was the relevance of "spatial" information given by RGB543 images about the uniformity of the crop inside of each individual plot. This information allows the users to gain confidence in the information, because they recognize in the image the variability of the crop along the plot due to differences on soil, irrigation, and other causes. As an example, Figure 2 shows the NDVI typical temporal evolution for a pivot of corn, and RGB543 images for three selected dates. It is possible to appreciate spatial differences inside the plot from the images. So it is very convenient that the information provided to the farmers combine qualitative aspects, in the way of image, and quantitative, about vigor and water requirement of crops.

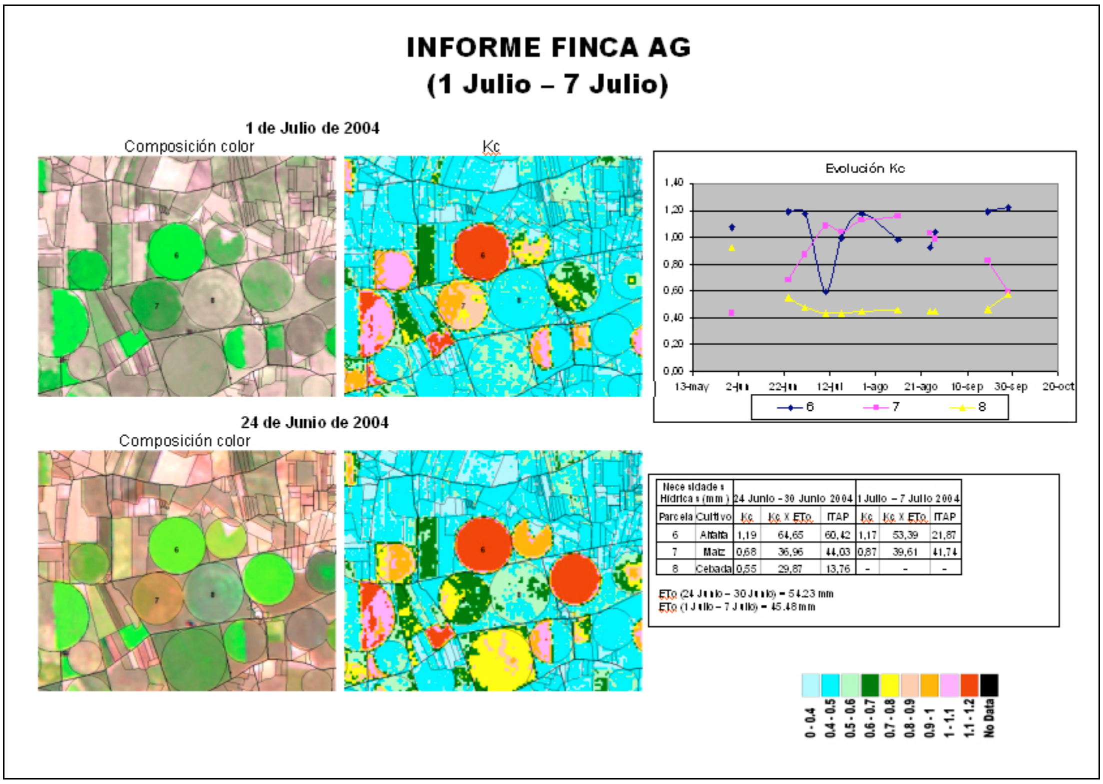


FIGURE 1. Example of Farmer's Report distributed weekly to farmers test group.

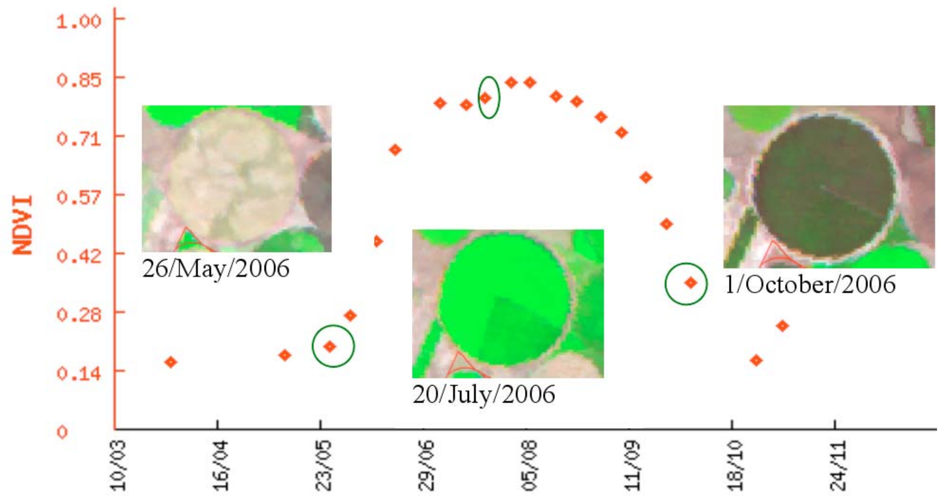


FIGURE 2. NDVI typical temporal evolution for a pivot of corn and selected RGB543 images for three dates where is possible to appreciate spatial differences inside the plot.

EVALUATION OF PRODUCTS AND SERVICES

We address both aspects of evaluation, the validation of DEMETER products in the technical-experimental context and the evaluation of DEMETER products and services in the users' environment.

Our assessment framework takes into account the different nature of the evaluation elements (information products, tools, and services), requiring a range of evaluation methods. We present here a summary of the Barrax pilot zone case study (see also Montoro et al., this volume). All elements ready for evaluation were assessed in a series of tests designed (a) to evaluate products delivered to IAS, (b) to evaluate tools developed for IAS use, and (c) to evaluate services provided to farmers.

A standard set of evaluation criteria is used in all cases (complemented with element-specific criteria as needed):

→ accuracy / quality:	"is at least as good as current"
→ added value:	provides new and useful information/capability
→ confidence:	at least as reliable as current, user trusts at least as current
→ cost:	less than current, affordable, brings more benefits
→ impact:	policy, environment, society, economy

Evaluation of Products Delivered To IAS

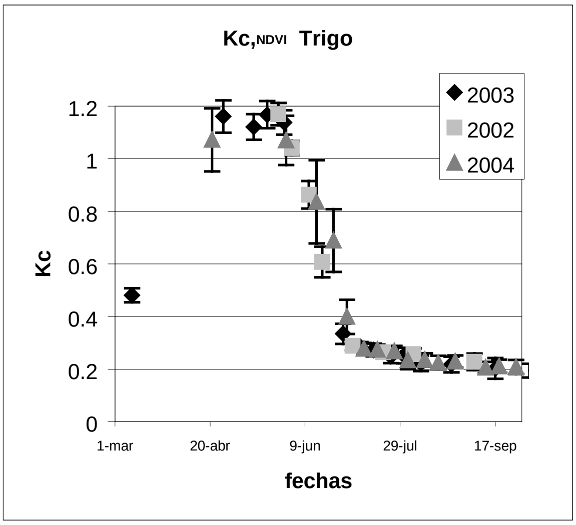
The **quality of EO-based per-crop K_c** was assessed during the 2003, 2004 and 2005 campaigns by means of comparison with ground truth data from field visits (weekly data for 600 plots), see extensive field campaign (WP5). Table 2 (from Calera et al. 2004; Cuesta et al. 2004) summarizes the results of the comparison. The EO-derived crop coefficients are in very good agreement with those from field work (FAO-56, updated with IAS observations for some crops) whenever the fractional ground cover of the crop is large. For sparse canopy crops (like onions and garlic), further local calibration is necessary to account for the soil evaporation effects. The overall K_c uncertainty within single crop types, like spring wheat, is shown to be less than 5% at any time (Figure 3).

The **accuracy of EO-based per-plot K_c** was assessed for selected plots and crop types by means of more detailed ground truth comparison, see González-Piqueras et al. (this volume). In the case of alfalfa, e.g., a substantial improvement over the current recommendation was achieved. In addition, mechanical errors introduced by the IAS technicians’ manual registration of very large amounts of data (600 excel sheets per week) are avoided.

TABLE 1. Comparison between the crop-averaged K_c values obtained from NDVI and the values for $K_{c,ini}$, $K_{c,mid}$ from FAO-56 for the main crops in the Barrax pilot zone. From Cuesta et al. (2004).

Crop	NDVI min	NDVI max	$K_{c,ini}$ EO	$K_{c,ini}$ FAO-56	$K_{c,mid}$ EO	$K_{c,mid}$ FAO56
Alfalfa	0.16	0.80	0.40	0.40	1.20	1.20
Barley	0.16	0.80	0.40	0.30	1.20	1.15
Garlic	0.16	0.44	0.40	0.70 (0.40)*	0.75	1.00
Maize	0.16	0.78	0.40	0.30 (0.40)*	1.17	1.20
Onion	0.16	0.53	0.40	0.70 (0.50)*	0.86	1.00
Opium poppy	0.16	0.80	0.40	No reference	1.20	No reference
Pea	0.16	0.77	0.40	0.50 (0.40)*	1.16	1.15
Potato	0.16	0.78	0.40	0.50 (0.45)*	1.17	1.15
Sugar beet	0.16	0.78	0.40	0.35 (0.45)*	1.17	1.20
Wheat	0.16	0.80	0.40	0.30	1.20	1.15

- *$K_{c,ini}$ values from IAS-ITAP*



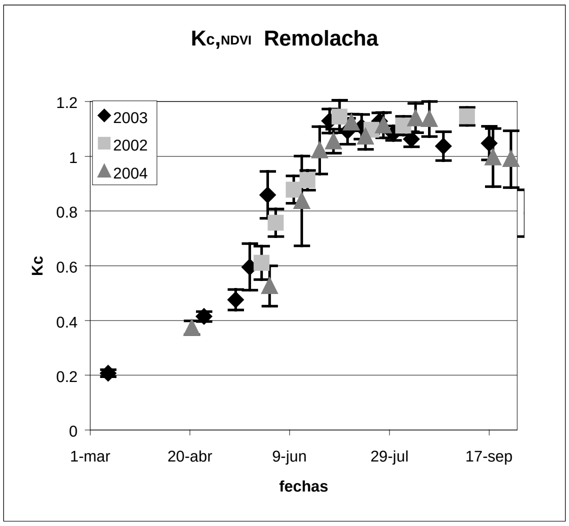


FIGURE 3. Temporal evolution of EO-derived crop coefficient for (a) spring wheat and (b) sugar beet. The symbols depict mean values of all corresponding fields during the 2002, 2003, and 2004 campaigns in the Barrax area. The error bars give standard deviation.

Added value information of the basic products results primarily from the extended spatial coverage (Table 2) and within-plot heterogeneity resolution (see section on evaluation by farmers below). The spatial information also allows the IAS Manager to detect anomalies or special features that occur in a certain part of the area.

Added value information is also provided by advanced products, like irrigation performance indicators (see Calera et al. 2005).

TABLE 2. Spatial coverage of current personalized service (by means of weekly visits of IAS technicians) and of DEMETER EO-based product (K_c maps) in Barrax pilot zone. EO is here based on high-resolution imagery (e.g., Landsat) with about 30 m pixel size, which can resolve plots larger or equal to 1 ha.

Covered by	Number of farms	number of plots	% of plots	Area (ha)
Field visits (current personalized service)	34	176	3,2	5.753
EO-based maps (30 m pixel size)	472	4.403	80,8	48.811
Total in pilot zone	477	5.450	100	49.348

Estimation of Costs

The annual cost of supplying an IAS with DEMETER basic products (K_c maps), mainly based on Landsat (interspersed with Spot as needed), was estimated on the grounds of 30 images per year per zone of 100.000 ha of irrigated land. The resulting cost for the entire area is on the order of 80.000 € per year (i.e., approximately 0,80 € per ha per year), with personnel cost for data processing and product generation accounting for about the same cost as image purchase.. Since the system provides automatically spatialized information, this cost covers both general (per-crop) and personalized (per plot) service to the whole area.

A comparable cost estimation was made for a traditional IAS (i.e., only the cost related to K_c data generation, not including the agromet stations). The resulting cost is on the order of 1,20 € per ha per year, covering the whole irrigated area in general mode (irrigation recommendation based on average per-crop values) and about 25% of the area in personalized mode (irrigation recommendation based on weekly technicians' visits to farm holding). Taking the personalized-mode area as a reference, the cost is 4,5 € per ha per year.

Knowing that some ground truth field work will always be necessary to support and quality-control an EO-based system, we still conclude from this first estimate that the EO-based service can operate at lower cost than a conventional IAS, while covering a significantly larger area in personalized mode.

Evaluation of Services Provided To Farmers

A small test group of farmers was set up during the 2004 and 2005 seasons. They received weekly the “Farmer’s Report” (see Figure 1). A series of meetings of this test group was held in order to collect their feedback. Their answers to the main enquiry issues are summarized in Table 3.

In particular, their opinion on accuracy of the EO-based products was surprisingly positive. A frequent comment was: “EO is objective, more accurate than what we currently get from any other source”.

TABLE 3. Feedback of farmers test group to weekly “Farmer’s Report” service. Scale of 1 to 5 from “not at all / very bad” to “very good / very much so”.	
Recognize spontaneously their plots and crops in color combination images and K_c maps (first time they see it)	All
Can deal with and approve of information content and format	All
Accuracy of data/information (see comments in text above)	5
Within-plot heterogeneity: recognize small-scale features known to them	5
Within-plot heterogeneity: discover new features	5
Information useful for farm management	5
Security concern (“others must not see data of my farm”)	All except one

The following main advantages of e-SAIAS over the IAS traditional system were reported by farmers in personal interviews: The new system incorporates information about spatial distribution inside a homogenous crop and this system enables a personalized temporal monitoring over a single plot. This great capability of temporal monitoring is limited by satellite coverage frequency, which can still be reduced by clouds presence. This situation is clearly put in evidence in the case of alfalfa, the fast growth of which (28 days growing cycle) would require a higher coverage frequency.

DISCUSSION

Demonstration of near-real-time acquisition, processing of satellite data and prototype basic EO products distribution to end users, evidences the capability of the e-SAIAS prototype to provide reliable and useful products to farmers about crop water requirement. The time of information delivery to users has been demonstrated to be (normally) one to (maximum) two days after satellite overpass. The operational processing and product generation chain, including quality control have been completely defined and verified. It requires a trained technician under technical expert supervision equipped with a normal remote sensing and GIS software running over a PC platform.

It has also been clearly evidenced during two demonstration campaign that the most vulnerable point in the chain production is the image supply in good conditions. The sensor failure in Landsat 7 (along with the uncertainty of continued operating capability of Landsat 5 and the missing long-term perspective of Landsat-type satellites) keeps being the most critical issue, affecting directly the operational concept of DEMETER, which largely relies and depends on Landsat.

The Landsat 7 failure clearly demonstrates the vulnerability of the operational space segment. Alternative platforms are less ideal for operations, since they are either much more expensive and/or image availability is much more complicated. However, discussions with Spotimage show that a combination of Landsat and Spot can be a feasible operational alternative in future years. For operational purposes in an area with smaller farms (like the Italian pilot zone, see d'Urso et al., this volume), Ikonos has proven to be a viable (yet more costly) option since it also provides the necessary higher spatial resolution in that area, with available rush service (24-hour delivery by FTP).

In order to account for unavailable satellite data (also due to cloudiness), a contingency scenario has been integrated in the prototype system. It bases the DEMETER operational system on a synergistic combination of EO data, field data, and an expert system of local K_c curves (developed from the synthesis of previous campaigns, specially tailored to the crops and climatology of a given pilot zone). In the case of an EO data failure (either missing image or clouds), the system would draw on a default list of K_c curves (per crop, crop cycle, sowing date) from (in order of priority) field data, the local expert system data base, and the FAO-56 tables (Allen et al., 1998).

SUMMARY AND CONCLUSIONS

The project DEMETER (DEMonstration of Earth observation TEchnologies in Routine irrigation advisory services) has been designed to assess and demonstrate improvements introduced by Earth observation (EO) and Information and Communication Technologies (ICT) in farm and Irrigation Advisory Service (IAS) day-to-day operations. The DEMETER concept of near-real-time delivery of EO-based irrigation scheduling information to IAS and farmers has proven to be valid. The operationality of the space segment was demonstrated for Landsat 5-TM in the Barrax pilot zone during the 2004 and 2005 irrigation campaigns. Extra-fast image delivery and quality controlled operational processing make the EO-based crop coefficient maps available at the same speed and quality as ground-based data (point samples), while significantly extending the spatial coverage and reducing service cost. First feedback of users at IAS and farmer level is encouraging.

The major improvement achieved by the use of EO in the generation of basic IAS information products like crop coefficients is twofold. Firstly, the spatial coverage is enhanced significantly, both extending to larger areas and providing within-field heterogeneity information. Secondly, the spatially resolved EO data can easily be combined with cadastral information in a geographical information system (GIS), which allows for personalization of the irrigation scheduling recommendation. Conventional IAS provide average irrigation recommendations per crop type, while the new space-assisted IAS is able to provide specific recommendations for each individual plot, based on the actual state of that plot.

The incorporation of leading-edge information technology gives rise to a qualitative and quantitative jump in the information supply to the farmer. It allows for transmitting not only the traditional irrigation scheduling information in improved and personalized form, but also a wide range of additional information that is of relevance to the farmer. The easy-to-use information products, transmitted to the farmer, are easily accessible and stimulate their use by the farmers. Farmers can opt to receive a wide variety of products, tailored to their needs and infrastructure, ranging from simple irrigation scheduling recommendation (irrigation volume, time) to color-coded images (providing quick intuitive information on the crop vigor within their plots), both on PC and/or mobile phones.

ACKNOWLEDGEMENTS

DEMETER (DEMonstration of Earth observation TEchnologies in Routine irrigation advisory services) is a shared-cost project, co-funded by the European Community under its Fifth Framework Programme ("Energy, Environment and Sustainable Development" Programme, contract EVG1-CT-2002-00078).

It is a collaborative effort of 17 partners: Universidad de Castilla-La Mancha (Spain) (coordination), Universitat de València (Spain), Instituto Técnico Agronómico Provincial (Spain), Ministerio de Agricultura, Pesca y Alimentación (Spain); Universitá degli Studi di Napoli "Federico II" (Italy), Consorzio di Bonifica in Destra Sele (Italy), Istituto Nazionale di Economia Agraria (Italy), Mestor SNC (Italy), Instituto de Meteorologia (Portugal), Associação de Beneficiários do Caia (Portugal), Instituto de Desenvolvimento Rural e Hidráulica (Ministerio da Agricultura, do Desenvolvimento Rural e das Pescas, Portugal), Universidade Trás-os-Montes e Alto Douro (Portugal), Chiron Sistemas de Informação LDA (Portugal), Université Louis Pasteur (Strasbourg, France), Centre National de la Recherche Scientifique (France), University of Thessaly (Greece).

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