Water resource management at district level. First results of AQUATER research project

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Abstract. An efficient management of water resources is a crucial point for Italy and in particular for southern areas characterized by Mediterranean climate in order to improve the economical and environmental sustainability of the agricultural activity.

AQUATER is a research project funded by the Italian Ministry of Agriculture, Food and Forestry Policies (2005-2009). It has the aim to develop a decision support system to integrate remote sensing information and crop simulation model to allow a best management of irrigation water at district scale. It is focused on the remote sensing, the plant and the climate and, for interdisciplinary relationships, the project working group consists of agronomists, engineers and physicists.

The Project is structured in four workpackages with specific objectives, high degree of interaction and information exchange: 1) Remote sensing and image analysis; 2) Cropping systems; 3) Modelling and softwares development; 4) Stakeholders.

In the paper the main results of the first two years of the Project are reported and briefly commented.

Keywords. Remote sensing – Evapotranspiration – Simulation model – Soil – Weather – DSS.

Gestion de l'eau au niveau du pèrimètre irrigué. Résultats préliminaires du projet de recherche AQUATER

Résumé. *Une gestion efficiente de la ressource en eau est cruciale pour l'Italie et en particulier pour les régions du sud, à climat méditerranéen, pour améliorer la durabilité des activités économiques et environnementales. AQUATER est un projet de recherche financé par le Ministère Italien de l'Agriculture (2005-2009). Il a comme objectif de développer un système pour intégrer les informations de la télédétection avec celles des modèles de simulation des cultures pour permettre une gestion de l'irrigation plus efficace au niveau du périmètre. Le projet met le point sur la télédétection, la plante, le climat et les relations interdisciplinaires, ainsi le groupe de travail du projet comprend agronomes, ingénieurs et physiciens. Quatre groupes de travail avec objectifs spécifiques et un haut degrée d'interaction s'échangent l'information qui couvre: 1) la télédétection et l'analyse de l'image; 2) l'assolement; 3) le développement des modèles et des logiciels; 4) stakeholders. Dans cet article sont présentés en bref les résultats principaux des deux premières années du projet.*

Mots-clés. *Télédétection – Évapotranspiration – Modèles de simulation – Sol – Climat – DSS.*

I – Introduction

Earth observation is reported as a tool in order to obtain information about land use, vegetation status, soil moisture, surface roughness and, in general, to estimate crop and soil information. Different methods have been developed to estimate evapotranspiration from remote sensing data, using energy balance equation and thermal infrared information. Basic and applied knowledge about crop water requirement are well documented, but the water distribution authorities need to have tools and support to best manage water at district level. Crop simulation models are mathematical representations of the soil-plant-atmosphere system, involving interactions between biological factors and environment. Spatially distributed models can be used also in simulation of basin, watershed or region.

A tool combining the above reported technologies could be very valuable for forecasting crop yield, water use, drought risk and to support irrigation authorities on decision about water management.

The AQUATER project, supported by Italian Ministry of Agriculture, Food and Forestry Policies (Rinaldi *et al.*, 2005) started in 2005 to develop and test methods for interpreting remote sensing data that could lead to a better evaluation of soil and vegetation functioning. The proposed approach is based on the assimilation of remote sensing data into soil and vegetation simulation models.

In the framework of the AQUATER project, the three largest plains of Southern Italy were monitored: Capitanata Plain, Sele river Plain and Ionic coastal Plain (Fig. 1).

The Project is structured in four workpackages:

A - Remote sensing and image analysis;

B - Cropping systems;

C - Modelling and software development;

D - Stakeholders.

The Working Units participating to the Project are:

- Agricultural Research Council – Research Unit for cropping systems in dry environments of Bari, with 5 sub-units and coordinating the Project;
- University of Napoli, Department of Hydraulic Engineering;
- National Research Council, Institute of Intelligent Systems for Automation, Bari;
- University of Milano, Department of Agriculture Production.

In this paper the preliminary results obtained during the first two years of the Project are summarized and reported according the four workpackages.

II – Results

1. Remote sensing and image analysis

Various earth observation techniques have been widely used in recent years to monitor the temporal and spatial variability of land use, plant canopy (LAI) and soil moisture (SWC), in order to estimate crop water requirements and assess drought risk. Optical sensors with different spatial and spectral resolutions have been extensively exploited to provide an estimation of LAI with satisfactory accuracy for most applications. However, cloud coverage may represent a strong limitation in using optical sensors for all the applications which require a frequent revisiting coverage. Active and passive microwave sensors have proven their potentiality for detecting SWC in several recent studies; in particular, space-borne active microwave imaging techniques are of special attractiveness thanks to their fine spatial resolution and the repetitiveness of measurements. In the AQUATER Project images obtained by both sensors have been acquired during crop growth cycle, processed and used: MERIS (resolution 300 m), LANDSAT TM (30 m), SPOT (20 m), IKONOS (4 m), in the optical, ASAR (30 m) and PALSAR (30) in the microwave region.

Firstly, to use remote sensed data for monitoring land cover it is very important to develop methodologies to obtain reliable maps. In order to achieve this objective a possible approach is to combine both “spectral” and “spatial” features characterizing each ground class. Fiorentino *et al.* (2006) and Castrignanò *et al.* (2008) proposed the integration of a spectral classifier for remote sensed data at medium resolution, based on a traditional statistical supervised classifier as "Maximum Likelihood", with the spatial information provided by a geostatistical tool, as "Indicator Kriging" algorithm. Using this combined approach, better results in land cover class discrimination have been obtained and the resulting maps look more homogenous than in the case with the spectral information only (Fig. 2).

Satalino *et al.* (2007, 2008) used a physically based method for mapping winter wheat using ASAR AP data, acquired at HH and VV polarization and at high incidence angles. The study analysed two temporal series of ASAR AP images, acquired in 2006 and 2007, over an agricultural area located in the Capitanata plain.

The wheat classification was obtained by applying an optimal threshold to the co-polarized backscatter ratio of ASAR AP data acquired during the peak growing stage. Classification accuracies on test data ranging between 75% and 80%, depending on the amount of spatial and temporal filtering performed, were obtained.

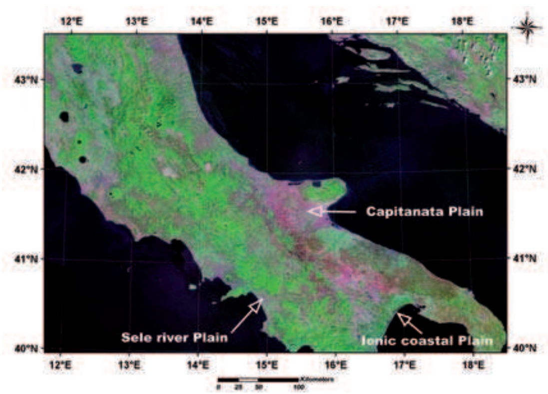

Figure 1. LANDSAT TM image with the indication of the three test areas of AQUATER Project.

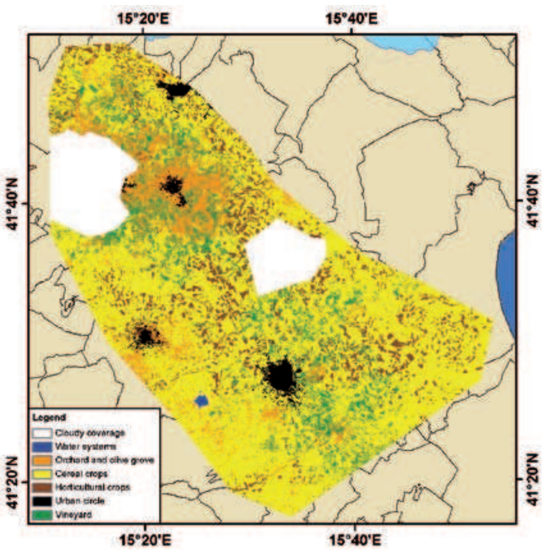

Figure 2. Land use maps in Capitanata plain, using the combined approach.

The obtained accuracies were not critically sensitive to the adopted threshold or to the specific acquisition date in the peak growing stage. In this respect, although optical data can provide higher level of classification accuracies, the proposed method appears robust and of particular interest for sites where the acquisition of cloud-free optical data is critical (Fig. 3).

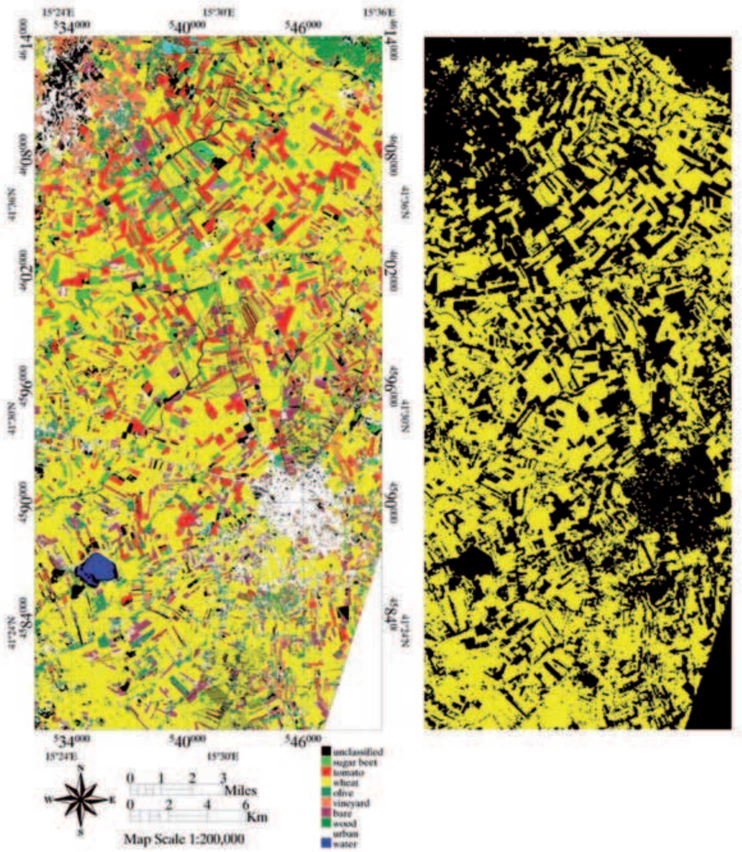

Figure 3. Classified image obtained from SPOT data (left). Wheat crop mapping obtained from ASAR data (right).

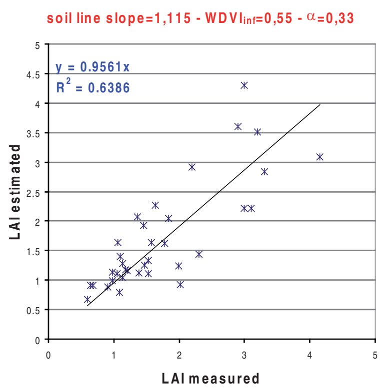

Figure 4. Relationship of estimated LAI from WDVI index and measured LAI of maize crop.

In the Sele river plain, the combined use of multi-temporal images LANDSAT and SPOT (June-August 2006) allowed to obtain land use, albedo and crop coefficients maps, in order to estimate seasonal crop water requirements. The relationship between Vegetation Index (VI) and LAI has been verified with good accordance using WDVI (Weighted Difference Vegetation Index) (estimated LAI vs. measured LAI: R2 = 0.64) (Fig. 4) (D'Urso *et al.*, 2008). Using other data-set the possibility to estimate from L-band SAR data, LAI and soil moisture in the upper soil layer has been positively evaluated (D'Urso *et al.*, 2007).

An algorithm transforming temporal series of ALOS-PALSAR SAR data into SWC by using a constrained minimization technique, integrating a priori information on soil parameters, has been developed (Satalino *et al.*, 2007). The algorithm has been applied to winter wheat and has been assessed on simulated and experimental data acquired during the 2006 and 2007 growing seasons over the site of Foggia. Two SWC maps referring to April 2 and May 18, 2007, are shown in Fig. 5. Preliminary results indicate the feasibility of retrieving volumetric soil moisture content with an accuracy of 5%.

2. Cropping systems

Systematic measurement campaigns at satellite overpassing have been carried out in 2006 and 2007 in the three experimental areas. To capture the main processes controlling soil-atmosphere exchanges, the local climate, soil and land use were fully characterized; surface energy fluxes, vegetation biomass and structure, soil moisture profiles, surface soil moisture and soil temperature were monitored. Additional spectral plant measurements and a full characterization of physical soil parameters were also carried out. The examined crops have been: durum wheat, tomato and sugar beet in Capitanata; water melon in Metaponto and maize in Sele river plain.

Continuous measurements of water status vegetation of crop let possible to schedule irrigation with the highest precision. Mainly in the Mediterranean regions the precision is required to use efficiently the water resources at field and regional levels. The first results support the hypothesis of identifying the vegetation water status based upon the relationship based on NDVI data. The existing data-set demonstrates that NDVI is also a function of the crop water status. The relationship between NDVI and pre-dawn leaf water potential (Ψ) is linear: $\Psi = 1.67NDVI-1.59$; $r^2 = 0.95$ (Fig. 6). From this relationship it seems possible to predict the crop water status starting from completely automatic measurements and, above all, from those ones that can be acquired through remote sensing techniques. Vice versa, the measurements of radiative temperature used to estimate the tomato water status proved to be unsatisfactory. The temperature of the vegetation, besides the soil water regime, is more dependent by meteorological conditions at the time of measurement (Mastrorilli *et al.*, 2008). A large database of climatic and pedological data have been acquired, also from previous projects, and quality control, georefentiation and harmonization have been carried out.

Delineation of broad soil zones within the study areas has been attempted using different soil and subsoil physical/chemical attributes. The multivariate data sets were submitted to an original combined approach of clustering, based on multivariate geostatistics linked to a nonparametric density function algorithm (Castrignanò *et al.*, 2008).

The proposed approach provided quite suitable to identify spatially contiguous zones, which are more homogeneous in soil properties than the whole area for both Capitanata and Ionic coastal plain (Fig. 7). Moreover, a 3D visualisation of the density function allowed to have an additional description of the residual within-cluster variation and then to judge the compactness of cluster.

Daily weather information has been recorded with automatic weather station. Eddy covariance method was used to measure actual crop evapotranspiration; the results showed how this latter measurement is well correlated to the evapotranspiration estimated with Penman-Monteith formula, but with less expensive equipment (Katerji and Rana, 2008; Ferrara *et al.*, 2008).

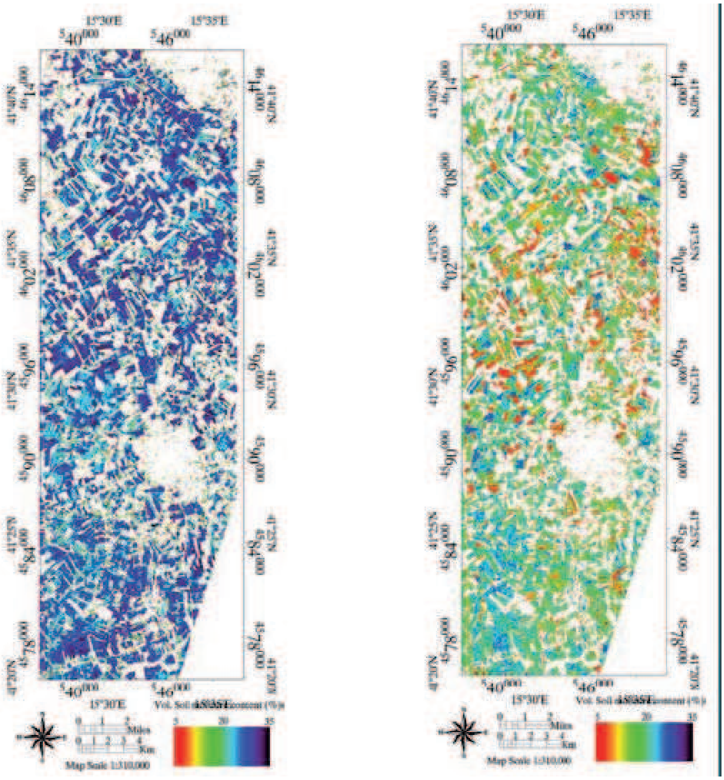

Figure 5. Soil moisture maps retrieved from PALSAR data over the Foggia site. The maps on the left and on the right refer to April 2 and May 18, 2007, respectively.

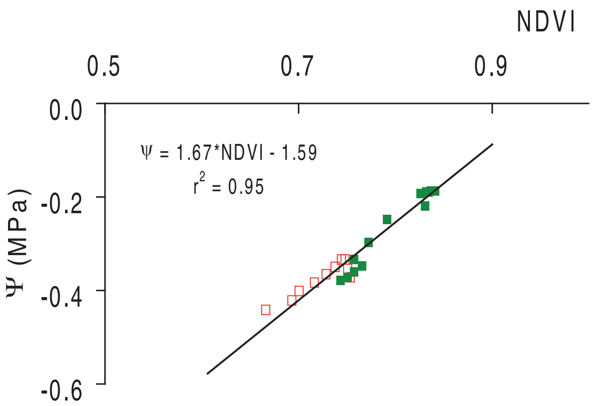

Figure 6. Pre-dawn leaf water-potential (Ψ) vs daily values of NDVI. Values derive from the full-irrigation (solid symbols) and the stressed (unfilled symbols) treatments.

Figure 7. Clustering of soil attributes in Ionian coastal plain.

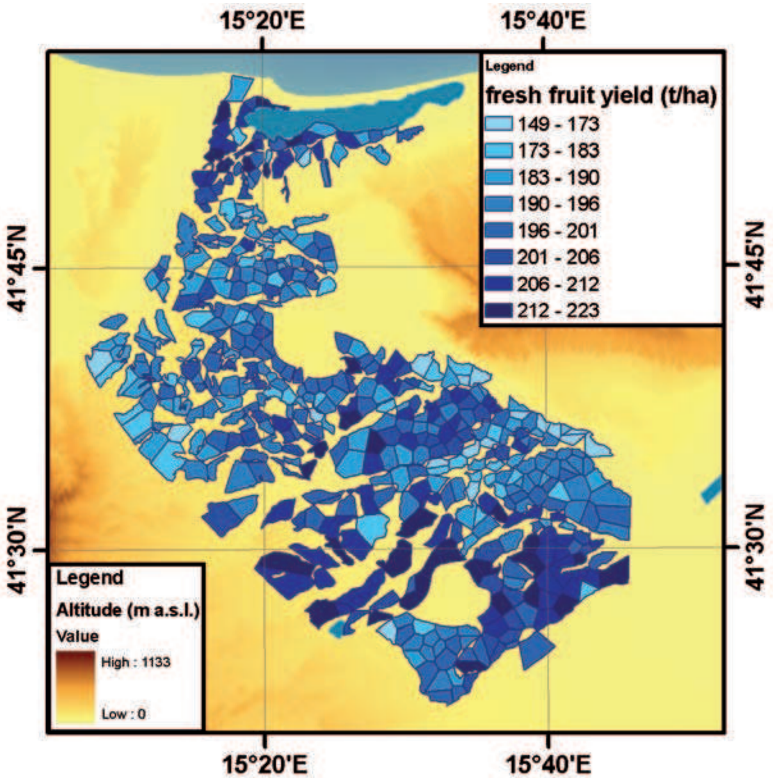

Figure 8. Distribution map of DSSAT simulated values of tomato fresh fruit yield irrigated at 45% of crop soil water in Capitanata plain.

3. Modelling and software development

Crop simulation models can appreciate "soil-climate-crop" interaction, offering stakeholders suggestions for better water allocation and advising farmers on the best irrigation scheduling from an economic point of view. In the AQUATER project several models have been used.

CropSyst model has been calibrated and validated for durum wheat and horse bean. The following application has been carried out simulating three cropping systems (durum wheat continuous cropping, 2-year and 3-year rotations with horse bean); a positive effect of leguminous crop on following wheat in rotation has been shown (higher soil water content at wheat sowing) (Garofalo *et al.*, 2007).

DSSAT crop simulation package and its GIS interface were used in some case-studies in Capitanata. Durum wheat and processing tomato have been simulated punctual-based using soil and long-term weather data (45 years). The two crops have been compared in the following management scenarios: rainfed and three automatic irrigation levels based on soil water content thresholds. GIS allowed visualising the output variables in the soil polygons. The wheat productivity was increased by irrigation of 19% and no difference occurred among automatic irrigation thresholds. In tomato the irrigation increased the yield by 3 times with respect to rainfed, with no difference among irrigation scenarios. The "soil x climate" interaction influenced the spatial response at regional level, allowing us to identify the area more productive for wheat and tomato (Fig. 8) (Rinaldi *et al.*, 2007;2008).

In Sele river and Metaponto coastal plains the physically-based model SIMODIS (SImulation and Management of On-Demand Irrigation Systems) has been applied on a data-base from another research project (SIGRIA, Inea), allowing to estimate seasonal irrigation volumes on maize and water melon at different spatial and temporal scales. This result, allowed to calculate some indicators of irrigation efficiency for the different soil classes, useful to save wastes in irrigation management at district scale (D'Urso *et al.*, 2008; Ventrella *et al.*, 2008). In Metaponto coastal plain SIMODIS has been also used to simulate the water melon crop. In particular, this approach was successful in estimating the main components of soil water balance. Analyzing the spatial distribution of these indicators it was possible to individuate the areas characterized by higher irrigation requirements and low water use efficiency due to water losses by deep percolation (Fig. 9). In general, the irrigation strategy of melon based on plant water status, allows to use water in a lightly more efficient way than the irrigation based on soil water status. However, with sand soil, characterized by very large value of saturated hydraulic conductivity, the best way to save water is to schedule the irrigation by monitoring the soil water content or adopting the evapotranspirometric method (Ventrella *et al.*, 2008).

Dente *et al*. (2006) developed a method to assimilate LAI maps retrieved from ASAR and MERIS remote sensing data into CERES-Wheat crop growth model in order to improve the accuracy of the wheat yield estimates at catchment scale. The assimilation leads to have information on the spatial variability of the yield in the area, which otherwise would have not been available. The assimilation method described in this work is a promising technique to apply crop growth models, such as CERES-Wheat, at catchment scale when no accurate in-situ information to run the model is available.

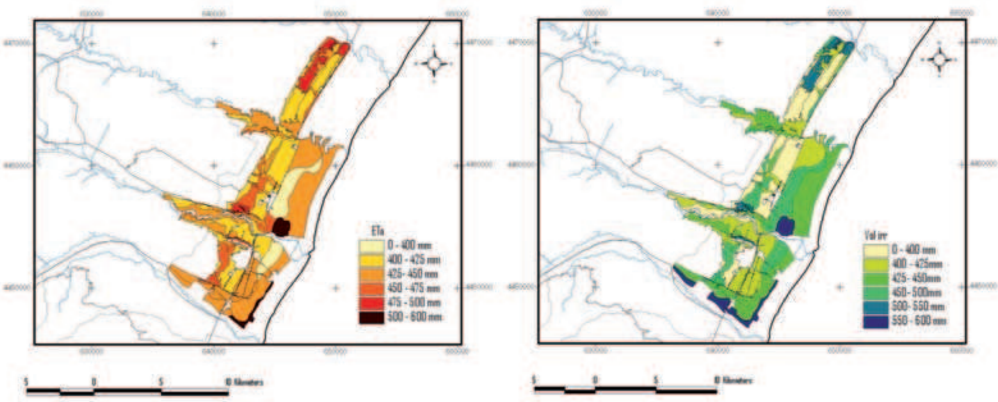

Figure 9. Spatial distributions of actual evapotranspiration (left) and irrigation depths (right) for Metaponto coastal plain.

A prototype of a Decision System Support (DSS) has been developed in order to schedule irrigation at district level in a Mediterranean area. The DSS uses the Unified modelling language and it integrates the information deriving from soil and climatic georeferenced database with a crop simulation model (STAMINA model), based on gross assimilation of CO_2 and on maintenance and growth respiration to get the final net carbon assimilation.

The software frame derives from the integration of interchangeable and extensible components and it has been developed for "Net" environment using VBNet and C# programming languages. Crop growth, water stress and water balance are simulated to estimate the water requirement and irrigation needs at regional level for different crops (until now only for sugar beet and maize). A set of input for the DSS, like crops and sowing dates, can be derived by remote sensing images. The LAI and plant biomass derived from remote sensing, can be further assimilated into the simulation model, to force the model to fit the values and to obtain an improvement of the simulation results. The DSS is at first prototype phase, but it is already provided of a GIS visualization tool. The first results obtained show the capabilities of the model that in the following research, will be further calibrated and validated with plant and soil experimental data. It will be improved also for the user interface, more friendly and easy to use (Acutis *et al.*, 2007; 2008).

4. Stakeholders

They represent the interface between "researchers" and "farmers" and, consequently, the exploiters of Project's results. They could give useful indications to the researchers about examined areas, and criteria for irrigation water management.

In the 2008 a 2-week training course about "Irrigation at new spatial scale" has been held in Foggia, at "Consorzio per la Bonifica della Capitanata" in Foggia, with 30 participants (technicians, graduate and Ph-students). The course has been structured in five main modules: 1) Soil-water relationships; 2) Crop water requirements; 3) New irrigation systems; 4) Modeling of the water balance processes; 5) Upscaling of the water balance processes.

III – Conclusion

The first results of the project have been shown and the real possibility to use the new technologies to efficiently manage water at district level resulted clear. In the ending part of the Project the third measurement campaign, the corroboration of relationships between vegetation indexes and bio-physical variables and the application of DSS, will be carried out.

Efforts could be done to improve the integration of different authorities – researchers, farmers, policy makers, and environmental agents - to share information and working together for a sustainable use of water in agriculture.

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