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I R R I M E D :
Improved management tools for water-limited irrigation:
combining ground and satellite information through models

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A ABSTRACT

The general scientific objective of IRRIMED is the assessment of temporal and spatial variability of water consumption of irrigated agriculture under limited water resources condition. Measurements with sophisticated equipments are used to combine ground and satellite data into models, to ultimately produce simple and robust methods to assess evapo-transpiration (ETR) over large areas

Two European institutions (IRD-cesbio, France ; WU, the Netherlands) associated with seven participants from four Mediterranean partner countries (Jordan, Morocco, Syria, Tunisia) have carried out the ambitious IRRIMED program through the following achievements:

- For each test site (one per MPC) a GIS based collection of all available information on soil, water, land use, through processing high resolution satellite imagery, particularly short time paced time series
- Performing micrometeorological measurements over fields representative of the main crops –in the 4 MPCs- while combining state of the art technology (eddy correlation and scintillometry) . Over most of the crop tested measured evapo-transpiration was found significantly lower than estimated from the literature
- Implementation and validation of a reference process model of water fluxes and vegetation growth used for benchmarking. Comparison and enhancement of robust and simple methods , applicable to satellite imagery (spatialized crop growth model SAFY)
- Application of simple method to satellite imagery to derive ETR maps and thus water consumption by the irrigated fields as observed from space (SAMIR prototype). Further developments for regional assessment by coupling with weather forecast and Meteosat data.
- Defining with the end-users through dedicated workshops and activities, their current needs and the specifications of a follow-up system for the operational implementation of the methods developed
- Ensuring the sustainability of the approach: capacity building through 3 international workshops gathering all young scientists to be trained on the main scientific issues of the project. This has been materialised by 9 PhDs thesis defended on the project research topics
- Wide dissemination of the results through a dedicated web site, with a querable publication data base, interactive illustrations, and on-line access to the workshop content and material

Following this success, the research will be pursued and applications developed, particularly within the PLEAIDeS project (FP6 GLOBAL4, 2006-2009)

B Summary of final report

IRRIMED is a research project conducted by 9 partners over 4 test sites in Jordan, Morocco, Syria and Tunisia, it combines ground and satellite measurements through models to better monitor and predict water consumption by irrigated crops.

In the context of water scarcity in the Mediterranean region, water managers -the main end-users of the results of this project- need to better monitor the irrigated areas in terms of acreages and crops planted, and in terms of water requirements, allocation and balance. Improved knowledge on all this aspects is the key for a better efficiency and to get “more crop per drop”.

This summary recaps the main project activities and results structured along 8 work packages

B.1 Building the information system [WP1].

On each of the four test sites a review of all existing background information has been performed to estimate the data availability and for assessing what is necessary to acquire for the project objectives. Thus, on each of the test sites ground and satellite data have been gathered, homogenized and formatted. For each of the two large ones (Jordan and Morocco) a specific GIS has been implemented. A major challenge is to get accurate and up to date land cover maps. Using time series of Landsat and Spot satellite images (acquired with support of CNES, France), the extent of the irrigated areas and the major crops could be distinguished through multitemporal analysis based on the crop calendar. This information is considered high priority by the end-users.

B.2 Micromet measurements [WP2].

Precise assessment of the actual consumption of water over common irrigated crops of the region (e.g.: wheat, olive and citrus in Morocco; tomato and alfalfa in Jordan) has been performed using the most advanced micrometeorological techniques. The “eddy covariance” method (EC), is nowadays the most accurate to measure the energy balance and water fluxes over a fields, it has been applied to all test sites over a variety of crops, representing the most cultivated ones. Each southern partner has acquired this sophisticated equipment and benefited from training both through the dedicated workshops and specific in-field assistance by partners 1 and 2.

Results of the EC measurements campaign clearly established that most of the values obtained using the standard values available from the FAO 56 manual, are overestimated. This is particularly true in the Jordan valley, where ETR values obtained with EC appeared between 20-30 % lower. As a conclusion of these experiments, acquiring actual ETR values is considered by end-users a very important step to improve irrigation management.

Scintillometry is a pioneering technique to measure heat fluxes over very large areas without having to put instruments in the middle of the field, but more conveniently at corners. Through experiments combining both EC and scintillometry on the same field (e.g. olives orchards in Morocco) it has been proven this technique is a powerful alternative, able to integrate fluxes over large areas. This provides a breakthrough towards bridging ground- with satellite measurements

B.3 Soil Vegetation Atmosphere Transfer models for water balance [WP3].

The dense field dataset obtained (including variables characterising plant development) has been used to feed a sophisticated Soil Vegetation Atmosphere Transfer model (SVAT) able to predict detailed water movements in the soil, trough the plants and towards the atmosphere. This reference SVAT model used here is the SISPAT is physically based and requires a large array of input data; it can be run only on the fully instrumented experimental plots. Its results in terms of evapo-transpiration (ETR) are then applicable at the corresponding irrigation district but not further

Simpler SVATs have been developed to obtain ETR with less measurements and involving less detailed physics (= shorter processing time), thus allowing to compute it over much larger area such as a full region. The simplification are made according to locally verified assumptions and checked against the reference model, and have led to the development of the ICARE model taking into account some specificities of the arid regions, in particular the need to describe separately the soil and the plant fluxes, such as in natural sparse vegetation or in tree plantations (see experiment over orange orchard) This simpler ICARE model was then further refined to take into account the surface temperature allowing future use of thermal directional measurements (either from ground or by satellite).

B.4 Simple models applied to satellite images: mapping ETR [WP4]

Validations over the various test sites (see measurements part of WP2) allowed defining the limitations and conditions of use of the simpler models. To establish links between these models and the parameters measured by satellites adapted to a per-field monitoring (i.e. high resolution optical sensors such as Spot or Formosat); emphasis was put on the biophysical parameters. Relationships between the crop development characterised by the Leaf Area Index (LAI) and vegetation indices where established.

Then simple models (such as SAFY) allowed modeling the crop development and predicting the ETR as well as overall biomass production. As a result maps of ETR of wheat over the Moroccan test site have been produced, and the overall grain production successfully estimated.

A simpler concept has been based on the FAO method using the Kc (crop development coefficient) to estimate ETR for a specific crop as a modulation of the local reference eva-potranspiration (ET0). In our approach, the crop development coefficient is not taken from published tabulated data, but in pseudo-real time from the vegetation index derived from satellite data. In the favourable case of easily available imagery (FORMOSAT images time series provided by CNES, France) intermediate values of Kc could be computed on a per pixel basis, leading to an estimation of the crop water requirements of an irrigation district at specific day, i.e. at a given stage of development. This approach has been implemented with partner 7 into a prototype of a monitoring software (SAMIR Satellite Monitoring of Irrigation). During discussions with the end-users and the final workshop on the implementation plan of the project results, this prototype as received a lot of attention and triggered hope, even if under the current situation the supply of appropriate satellite imagery is not yet routinely available.

B.5 Testing scenarios [WP5].

The idea was here to elaborate various potential scenarios for the future of irrigated agriculture in the studied areas (using inputs from socio-economic expertise outside the project), and to test what kind of impact we can predict applying the water demand models developed within the project

The expertise available allowed considering two main types of scenarios:

- **Better use of existing water**. An experiment conducted by partner 7 on wheat, compared flood irrigation based upon availability with same type of irrigation but "on demand" following the planning of FAO method. Results showed that given today's condition irrigation on demand shows a strong benefit on crop yield (+28%), but no water saving. In another experiment 20% water saving was obtained using drip irrigation
- **Taking climate into account**. Using the SAMIR software and climate data from the ALADIN model (DMN, Morocco) the impact of climate variations on the evaporative demand (ET0) has been tested and the consequences on water demand estimated.

These first attempts of applying various scenarios have demonstrated the benefit of improving irrigation techniques and of monitoring software for better management. They will be refined in follow-up projects.

B.6 Involving the end-users: needs and requirements [WP6].

The end users have been involved since the beginning of the project through meetings to take into account their requirements on the type of information they would like to gain from the project. This can be rather different from what the scientists need and would love to produce. From the technological point of view, the methods developed have been indeed following these main requirements:

- Assessing the irrigation and crop extent, through the use of satellite data combined in multitemporal sets
- Better assessment of Crop water requirements in the field and their spatialization with satellite data

The next step of the implementation will be deployed within new undergoing projects, with two major enhancements towards a wider use:

- Better portability: use of a non proprietary (generic) computer code, easy to access and tailor to different users needs
- Better access: the application will be implemented in web server to allow users to access it directly through the internet (for the public part, access rights will be implemented for specific data)

B.7 Capacity building, technology transfer and dissemination [WP7].

A strong emphasis is put on the capacity building through workshops, north south and south-south student exchanges and scientific discussions. The idea is to have the SMEs institutions in the position to pursue by themselves the research and developments undertaken when IRRIMED will be finished. In addition to exchanges and visits of scientists, an intense training programme has been developed:

- The **first** training workshop in Palmyra, Syria. Organised by ACSAD in the historical oasis of Palmyra. During 5 full days, 33 participants from 6 countries involved in IRRIMED have followed the lectures and practiced hands-on exercises on micro-meterological methods for measuring evapo-transpiration over crops. exchanges and training
- The **second** training workshop hosted in Amman by partner 3, the College of Agriculture of the University of Jordan, has been dedicated to the remote sensing aspects (led by CESBIO-IRD, partner1). During 4 days, the participants from all southern partner countries have followed the lectures and practiced hands-on exercises on satellite image processing for mapping evapo-transpiration over crops.
- Scientists and trainers have also interacted with the **end-users** during **two special workshops** organised by the Ministry of Water and Irrigation as part of work package 6 (see partner 5 report).
- The *third* IRRIMED Workshop on « crop water modelling tools ». Hosted in Hammamet Tunisia by partner 9 (INRGREF) , IRRIMED workshop Tunis, November, 28th to December 2nd 2005 has been led by CESBIO-IRD (partner1),

B.8 Scientific steering and information management

As part of the coordination activities, two prominent types of activities have been a) the organisation of the annual meetings and of the scientific workshops, and b) in addition to the financial and scientific reporting, the large effort to promote the project science and results through the web site, featuring a querable library containing more than 200 project publications

(see http://www.irrimed.org)

B.9 Conclusion

The main benefits of the project can be summarised as:

- new knowledge on the evapo-transpiration assessment in the field, development of models predicting ET and crop development, simplified versions used in combination with satellite to obtain biomass and ET maps (numerous peer reviewed publications)
- intense transfer of know-how and technology through 3 international workshops gathering the young scientists in Syria, Jordan and Tunisia (with hands-on exercises and internet support)
- strong involvement of the end-users as full stakeholders in the project deployment, adjustment of the objectives and methods to their actual needs
- Reinforcement of north-south, but also south-south cooperation in the building a scientific community spirit around the theme of monitoring agricultural water in the Mediterranean region.

B.10 Most Important project publications

B.10.1 Ph D. thesis

ABOURIDA, A. (2007). Approche hydrogéologique de la nappe du Haouz (Maroc) par télédétection, isotopie, SIG et modélisation. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad (Morocco) , 196 p.

CHAPONNIÈRE A.(2005) Fonctionnement hydrologique d'un bassin versant montagneux semi aride. Cas du bassin versant du Rehraya (Haut Atlas marocain) Institut National Agronomique de Paris Grignon, 268 p.

ER-RAKI, S. (2007). Estimation des besoins en eau des cultures dans la région de Tensift AL Haouz : Modélisation, Expérimentation et Télédétection. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad (Morocco), 128 p.

EZZAHAR, J. (2007). Spatialisation des flux d'énergie et de masse à l'interface Biosphère-Atmosphère dans les régions semi-arides en utilisant la méthode de scintillation. *UFR : Thermique et Mécanique des Fluides*. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad. (Morocco), 115 p.

HADRIA, R. (2006). Adaptation et spatialisation du modèle STICS pour la gestion d'un périmètre céréalier irrigué en milieux semi aride. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad (Morocco). , 216 p.

HARTOGENSIS, O. (2006). Exploring Scintillometry in the Stable Atmospheric Surface Layer. Wageningen, Netherlands, Wageningen University, 240 p.

HOEDJES, J. (2007). Estimation de l'Evapotranspiration sur des Surfaces Irriguées en Zones Semi-arides : Combinaison Modélisation, Télédétection et Scintillométrie. Toulouse, France, Université Paul Sabatier (UPS), 167 p.

JITAN, M. (2005). Eva-potranspiration of major crops in the Jordan Valley using Remote Sensing techniques compared with estimated field measurement using Eddy-Correlation. Thèse, University of Jordan, Amman, Jordan, 235 p.

MERLIN O. (2005) Synergie des observations multispectrales : Application en hydrologie. Spécialité Télédection et Hydrologie. Université Paul Sabatier - Toulouse-III. 152 p.

B.10.2 Articles in peer reviewed international journals

Baret, F., Weiss, M., Allard, D., Garrigue, S., Leroy, M., Jeanjean, H., Fernandes, R., Myneni, R., Privette, J., Morisette, J., Bohbot, H., Bosseno, R., Dedieu, G., Di-Bella, C., Duchemin, B., Espana, M., Gond, V., Gu, X., Guyon, D., Lelong, C., Maisongrande, P., Mougin, E., Nilson, T., Veroustraete, F., and Vintilla, R. (?). VALERI: a network of sites and a methodology for the validation of medium spatial resolution land satellite products. *Remote Sensing of Environment*, in press.

Boulet, G., Chehbouni, A., Gentine, P., Duchemin, B., Ezzahar, J., and Hadria, R. (2007). Monitoring water stress using time series of observed to unstressed surface temperature difference. *Agricultural and Forest Meteorology*, in press.

Er-Raki, S., Chehbouni, A., Guemouria, N., Duchemin, B., Ezzahar, J., and Hadria, R. (2007). Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region. *Agricultural Water Management* **87**, 41-54.

Ezzahar, J., Chehbouni, A., Hoedjes, J., and Chehbouni, A. (2007). On the application of scintillometry over heterogeneous grids. *Journal of Hydrology* **334**, 493-501.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Er-Raki, S., Chehbouni, A., Boulet, G., Bonnefond, J., and De-Bruin, H. (2007). The use of the scintillation technique for monitoring seasonal water consumption of olive orchards in a semi-arid region. *Agricultural Water Management* **89**, 173-184.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Er-Raki, S., Duchemin, B., and Chehbouni, A. (2007). The use of the Scintillation Technique for estimating eva-potranspiration ET over several agricultural fields in semi-arid region. *Plant Biosystems*, submitted.

Hadria, R., Khabba, S., Lahrouni, A., Duchemin, B., Chehbouni, A., and Carriou, J. (2007). Calibration and Validation of the STICS Crop Model for Managing Wheat Irrigation in the Semi-Arid Marrakech/Al Haouz Plain. *Arabian Journal for Science and Engineering* **32**, 87-101.

Simonneaux, V., Duchemin, B., Helson, D., Er-Raki, S., Olioso, A., and Chehbouni, A. (2007). The use of high-resolution image time series for crop classification and eva-potranspiration estimate over an irrigated area in central Morocco. *International Journal of Remote Sensing*, in press.

Duchemin, B., Hadria, R., Er-Raki, S., Boulet, G., Maisongrande, P., Chehbouni, A., Escadafal, R., Ezzahar, J., Hoedjes, J., Kharrou, M., Khabba, S., Mougenot, B., Olioso, A., Rodriguez, J.-C., and Simonneaux, V. (2006). Monitoring wheat phenology and irrigation in Central Morocco : on the use of relationship between eva-potranspiration, crops coefficients, leaf area index and remotely-sensed vegetation indices. *Agricultural Water Management* **79**, 1-27.

Er-Raki, S., Chehbouni, A., Guemouria, N., Duchemin, B., Ezzahar, J., and Hadria, R. (2006). Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region. *Agricultural Water Management* **87**, 41-54.

Hadria, R., Duchemin, B., Lahrouni, A., Khabba, S., Er-Raki, S., Dedieu, G., Chehbouni, A., and Olioso, A. (2006). Monitoring of irrigated wheat in a semi-arid climate using crop modelling and remote sensing data : Impact of satellite revisit time frequency. *International Journal of Remote Sensing* **27**, 1093–1117.

Merlin, O., Chehbouni, A., Kerr, Y., and Goodrich, D. (2006). A downscaling method for distributing surface soil moisture within a microwave pixel: Application to the Monsoon '90 data. *Remote Sensing of Environment* **101**, 379-389.

Coret, L., Briottet, X., Kerr, Y., and Chehbouni, A. (2005). Experimental study of the directional aggregation of radiance and temperature over heterogeneous surface in the thermal infrared. *Remote Sensing of Environment*

Hagolle, O., Lobo, A., Maisongrande, P., Cabot, F., Duchemin, B., and De-Pereyra, A. (2005). Quality assessment and improvement of temporally composited products of remotely sensed imagery by combination of VEGETATION 1 and 2 images. *Remote Sensing of Environment* **94**, 172-186.

Merlin, O., Chehbouni, A., Kerr, Y., Njoku, E., and Entekhabi, D. (2005). A Combined Modeling and Multispectral/Multiresolution Remote Sensing Approach for Disaggregation of Surface Soil Moisture : Application to SMOS Configuration *IEEE Transactions on Geosciences and Remote Sensing* **43**, 2036-2050.

Boulet, G., Chehbouni, A., Braud, I., Duchemin, B., and Lakhal, A. (2004). Evaluation of a two-stage evaporation approximation for contrasting vegetation cover. *Water Resources Research* **40**, W12507.

Coret, L., Briottet, X., Kerr, Y., and Chehbouni, A. (2004). Simulation Study of View Angle Effects on Thermal Infrared Measurements over Heterogeneous Surfaces. *IEEE Transactions on Geosciences and Remote Sensing* **42**, 664-672.

De-Bruin, H., and Hartogensis, O. (2004). Variance method to determine turbulent fluxes of momentum and sensible heat in the stable atmospheric surface layer. *Boundary Layer Meteorology* **116**, 385-392.

De-Bruin, H., Hartogensis, O., Allen, R., and Kramer, J. (2004). Regional Advection Perturbations in an Irrigated Desert (RAPID) experiment. *Theor. Appl. Climatol.* **80**, 143-152.

Dedieu, G., Chehbouni, A., Menaut, J., Boone, A., Ceschia, E., Coret, L., Gouaux, P., Hoedjes, J., Maisongrande, P., and De-Rosnay, P. (2004). Integrated approach of land surface functioning at the regional scale: the hows and whys from the "sud-ouest" project experience. *In* "1st General Assembly of European Geosciences Union (EGU)", pp.?, Nice, France.

Ezzahar, J., Chehbouni, G., Hoedjes, J., Er-Raki, S., Lakhal, A., Rodríguez, J.-C., Chehbouni, A., Boulet, G.,

Hartogensis, O., and De-Bruin, H. (2004). Monin-Obukhov similarity functions of the structure parameters of temperature and turbulent kinetic energy dissipation rate in the stable boundary layer. *Boundary Layer Meteorology* **116**, 253–276.

Hoedjes, J., Chehbouni, A., Ezzahar, J., Gentine, P., Boulet, G., Duchemin, B., Escadafal, R., Simonneaux, V., De-Bruin, H., Dedieu, G., Su, Z., and Troch, P. (2004). An evaluation of two methods for the validation of models for the estimation of surface fluxes. *In* "1st General Assembly of European Geosciences Union (EGU)", Vol. 6, pp. 04703. European Geosciences Union, Nice, France.

Maisongrande, P., Duchemin, B., and Dedieu, G. (2004). VEGETATION/SPOT - An Operational Mission for the Earth Monitoring : Presentation of New Standard Products. *International Journal of Remote Sensing* **25**, 9-14.

Merlin, O., and Chehbouni, A. (2004). Different approaches in estimating heat flux using dual angle observations of radiative surface temperature. *International Journal of Remote Sensing* **25**, 275-289.

Pellenq, J., and Boulet, G. (2004). A methodology to test the pertinence of remote-sensing data assimilation into vegetation models for water and energy exchange at the land surface. *Agronomie* **24**, 197-204.

Rodriguez, J.-C., Duchemin, B., Hadria, R., Watts, C., Garatuza, J., Chehbouni, A., Khabba, S., Boulet, G., Palacios, E., and Lahrouni, A. (2004). Wheat yield estimation using remote sensing and the STICS model in the semiarid Yaqui valley, Mexico. *Agronomie* **24**, 295-304.

Pellenq, J., Kalma, J., Boulet, G., Saulnier, G., Wooldridge, S., Kerr, Y., and Chehbouni, A. (2003). A disaggregation scheme for soil moisture based on topography and soil depth. *Journal of Hydrology* **276**, 112-127.

C Consolidated scientific report

C.1 Objectives

IRRIMED rationale

Existing water resources in the SMEs countries are unlikely to increase significantly, some climate change scenarios even predict scarcer and more erratic precipitations, whereas the fossil aquifers are already overexploited. Thus, the only way to impact positively the irrigated agricultural production is to increase the efficiency of the uses of water through the improvement of the management of existing resources. Better management presupposes better tools to assess the resource and to follow its actual use.

IRRIMED research is conducted by 9 partners over 4 test sites in Jordan, Morocco, Syria and Tunisia, it combines ground and satellite measurements through models to better monitor and predict water consumption by irrigated crops. The research plan is structured along 8 workpackages (WPs)

Main project objectives

- On each of the four test sites a review of all existing background information is performed, to estimate the current data availability variability, and for assessing what is necessary to acquire for the project objectives (this is different from end-users requirements, see below) [WP1].
- Precise assessment of the actual consumption of water over the most common irrigated crops (e.g.: wheat, olive and citrus in Morocco ; tomato and alfalfa in Jordan) is performed using the most advanced micromet techniques (eddy covariance and scintillometry) [WP2].
- the dense field dataset obtained (including variables characterising plant development) is used to feed a sophisticated Soil Vegetation Atmosphere Transfer model (SVAT) able to predict detailed water movements in the soil, trough the plants and towards the atmosphere. This *reference SVAT* is physically based and requires a large array of input data, it can be run only on the fully instrumented experimental plots. Its results in terms of evapotranspiration (ETR) are then applicable at the corresponding irrigation district but not further [WP3].
- Simpler SVATs are developed to obtain ETR with less measurements and involving less detailed physics (= shorter processing time), thus allowing to compute it over much larger area such as a full region. The simplification are made according to locally verified assumptions and checked against the reference model. Validations allows to define the limitations and conditions of use of the simpler models [WP4].

  Satellite imagery is used as source of spatially distributed information on plant condition (Leaf Area index, for instance) and the simple models can then be applied to each pixel to compute a raster map of ETR [WP4].
- The idea is here to elaborate various potential scenarios for the future of irrigated agriculture in the studied areas (using inputs from socio-economic expertise

outside the project), and to test what kind of impact we can predict applying the water demand models developed within the project [WP5].

- The end users are involved through meetings to take into account their requirements on the type of information they would like to gain from the project. This can be rather different from what the scientists need and would love to produce [WP6]. It will be defined in conjunction with the ability to adapt the answers of the models developed to various scenarios of interest for decision makers and irrigation planners [WP6].
- finally a strong emphasis is put on the capacity building through workshops, north south and south-south student exchanges and scientific discussions. The idea is to have the SMEs institutions in the position to pursue by themselves the research and developments undertaken when IRRIMED will be finished [WP7].

C.2 Review of project activities

C.2.1 WP 1 : building the information system

On each test site data relevant for this study has been gathered, synthesised and formatted then implemented in a Geographic Information System (GIS), the corresponding effort being tailored to the size of the sites, the largest are in Morocco and in Jordan.

Over the Moroccan test site, thanks to the already existing cooperation between partner 1 and 7, the different layers of the information system (geology, soils, land cover, irrigation network, hydrogeology, climate, administrative limits) have been established during the first year. The second year efforts have been focused on improving the land cover map, and particularly on distinguishing tree planted fields (such as olive and citrus orchards) from the annual crops, using high resolution satellite imagery. In combination with the soil information synthesized from the heterogeneous data set available over the whole area, this allows to refine the overall water consumption estimates based on the WP4 (see further and partner 1 report).

The University of Jordan (partner 3) has fully developed the crop inventory initiated during the first year, using the special set of SPOT high and very high resolution has been ordered by CESBIO (partner 1) from the CNES. Combining it with ground collected data, the team has been refining classification techniques to obtain high-resolution ‘per field’ crop classes.

This is a significant progress in the crop monitoring of the Jordan valley as no data exist so far with this level of details.

During the last year this work package has benefited from an additional satellite data input experiment. Over the Moroccan test sites specific time series of high resolution satellite data have been acquired through special programmes of CNES (French Space agency). A series of Formosat images allowed to closely monitor the crop development during the season oct 05 to summer 06. Field observations and measurements where performed during the same time. The data sets obtained have been used to refine the approach developed in WP4.

C.2.2 WP2 Micromet measurements

These measurements have been essential to the project as they address two very important points:

- Improve the computation of reference evapotranspiration (ET0)
- Assess the actual evapotranspiration over representative crops in the real local conditions of the IRRIMED test sites and regions

These measurements have been intensive during the first year and continued during year two on different crops, and on all sites (see individual reports). The objective is to assess actual evapotranspiration over the main representative crops of the region. One of the use of these data is to verify and update the Kc coefficients of the FAO method (e.g. see the interesting results of Partner 4 obtained over sweet corn), the others being the calibration of the more detailed and physically based models (see next WP).

During the third year new crops have been subjected to full micromet measurements (with the Eddy Correlation method), particularly a full data set has been acquired over citrus in Morocco, over potatoes in Jordan and over oat in Tunisia. In Syria a dedicated experiment has allowed to compare ET over the oasis with the nearby Sebkha.

Experiments have been conducted with strong collaborative dimension, all partners being involved by the WPs leaders and through the scientific coordination, to this respect the fostering effect of the two dedicated training workshops has been striking.

Partner 2 in charge of this WP has also pursued with partner 1 and 6 the refinement of the methods and intercomparison of the two main current approaches based on one side on “eddy correlation” and on the other side on “scintillometry”. The data set of the first experiment over the Agdal olive orchard in Morocco (Marrakech region) has been used and a new experiment has been designed to see the effect of a mosaic of crops on scintillometric measurements, and how to estimate average fluxes over mixed land surfaces (see also partner 1 report).

In parallel, partner 2 in charge of this workpackage has pursued methodological research on two other points: method to derive ET0 from Meteosat date (MSG) and improvement of the theoretical background and application of long range scintillometry (XLAS) allowing to measure Heat flux over wider areas (transect of typically 10 km).

C.2.3 WP3 reference models

Several models are implemented within WP3 to compute estimates of the various components of the water balance. However, models that compute all the components of the surface water balance, are usually complex. They are used here as "reference" point-scale models, but they rely on a large number of parameters that are difficult to asses outside a comprehensive experimental set-up. On the other hand, simple "operational" models designed for the regionalisation of the water balance describe only parts of the transfer processes, and rely on many semi-empirical relationships that cannot take into account all climates, soils, vegetation and irrigation types.

Data collected over three moroccan sites have been used in the model intercomparison exercises (the Agdal olive tree site, the R3 wheat site and the Saada orange tree site). Four Soil-Vegetation-Atmosphere-Transfer models of different complexity (SiSPAT, ICARE-SVAT, SVATsimple and the FAO56 method) have been applied to these 3 datasets, in order :

1. To compare the performances of the physically based simple SVAT model implemented during WP3 (SVATsimple) to a very complex SVAT model (SiSPAT), for different vegetation densities; the results of this study have been published in Boulet et al. (2004ab).
2. To build on previous model performance studies using newly available datasets (A. Lakhal's PhD, directed by L. Lakhal and G.Boulet)
3. To investigate whether the Thermal Infra Red remote sensing data can be assimilated into the SVATsimple model to detect second-stage evaporation processes and retrieve soil moisture status.

Among the findings of the analysis of the results of the modelling exercise, the FAO56 method appears estimating correctly the ETR (over wheat and olive) on the Moroccan test site, using locally adjusted Kcs. When trying to use the refined 'dual' version there is no real improvement, the ET is correctly estimated but the method fails at predicting the partition between transpiration and evaporation, which is the aim of the dual approach.

The benefit of physical modelling lies then not in the global estimation of ET, but more in a better partitioning. This aspect is crucial when trying to improve the water efficiency as one tries to minimise the evaporation and maximise transpiration. However the water applied which is not used by the plant transpiration is not necessarily all wasted or 'lost', some evaporates indeed directly from the soil, but some might be percolating allowing leaching of the soil and even feeding the water table.

Another important activity has been an experiment dedicated to adapt the modelling effort to non-continuous vegetation covers. Thus, in order to check whether a Soil-Vegetation-Atmosphere Transfer model, ICARE, has the adequate description of the energy and water budget components in the case of semi-arid sparse vegetation stands, an experimental set-up was designed and installed at the Saada2 orange orchard within the Moroccan test site areat. In particular, a series of radiometers and heat flux plates were installed to sample the variability in surface temperature and ground heat flux. The objectives of this experiment were:

- to document the heterogeneity of the water and energy balance of a sparse orchard;

- to check the ability of current Soil-Vegetation-Atmosphere models to reproduce/take into account/bypass this heterogeneity prior to assimilation

C.2.4 WP4 spatialisation using remote sensing

The objective of work package 4 was to integrate ETR simplified model into GIS (land cover, soil/meteo) with satellite data. Prerequisite is land cover mapping (WP1) and crop development monitoring (vegetation dynamics and crop coefficients).

Using the benchmarking and validation of simpler SVAT models of WP3, the objective here is to design methods applicable to images on a per pixel basis, what we call spatializing, it has been covered by three main activities (involving partners 1,3, 6 and 7):

1. development of a model more explicitely linking the photosynthetically active radiation absorbed by the plants, to the production of dry phytomass (SAFY model, 'Simple Algorithm For Yield estimates'). This has been done for irrigated wheat crops, taking benefit of the data collected on the moroccan test site over several field during two successive agricultural seasons : 2002/2003 (used for calibration) and 2003/2004 (used for validation). In parallel, the STICS crop developed at INRA-France was tested on the same experimental conditions.
2. monitoring crop development: a time series of 20 high spatial resolution images (SPOT and Landsat) has been acquired during the period from November 2002 (sowing period) to June 2003 (harvest period). After cloud screening the remaining 10 images were geometrically and atmospherically corrected to extract the 3x3 km² square area of interest where the land cover was controlled field by field. The comparison of images and field data allowed to establish relationship between remotely-sensed vegetation indices biophysical variables such the leaf area index and the vegetation fraction cover, which are of particular importance for the monitoring of soil-vegetation-atmosphere water exchanges.
3. spatializing Actual Evapotranspiration (AET): the previous findings were used to provide estimates of crop coefficients used in the FAO-method for inferring AET. The mapping of crops coefficients were performed at two space scales: the 3x3 km² square area of interest, with a focus on wheat crops; and the Al Haouz/Marrakech plain. The use in conjunction of land use maps, vegetation models and time series of images allowed to provide continuous estimates of crop coefficients during the 2002-2003 agricultural season.

Over the Jordan Valley test site, the Jordanian team used the high resolution land use map they established (see WP1) to identify crops and follow their development. In a similar manner to what has been done on the moroccan Haouz plain, the potential of NDVI profiles (vegetation index) for ET monitoring and mapping has been demonstrated.

Thanks to the convincing results obtained in the first phase of the programme, this workpackage has been expanded during the last 18 months within two directions :

1 refine the analysis of the satellite data requirements by using more recent and advanced imagery. As a contribution to WP1 two specific CNES-funded experiments have been set up on two project test areas, and their processing for the spatialisation of ET is part of WP4.

   a. Very high resolution FORMOSAT satellite data have been acquired over the Al Haouz/Marrakech plain. The images provided by this Tawainese satellite cover 24 x 24 km² scene at 8m resolution with a constant viewing angle. A total of 30 cloud-free images (out of 65 acquisitions) has been acquired from November 2005 to June 2006 (corrected with water vapour and aerosol data collected with a CIMEL sun photometer).

b. 12 High resolution SPOT images acquired over the Jordan Valley (see WP1, partner 3), have allowed to refine the crop identification (including greenhouses). The conversion into ground reflectances has been the first step towards the use of these images to compute ET for some selected crops, testing spatialisation techniques for the Jordan case

2 pursue the development of the software dedicated to the mapping of crop evapotranspiration using satellite images and simple vegetation models. This has lead to the SAMIR prototype developped in IDL langage and integrated in the ENVI satellite image processing software (see details in partner 1 report).

C.2.5 WP5 : building and testing scenarios

Several factors likely to trigger evolutions of irrigated agriculture can be listed:

- change in climate (probably dryer in most of the north African countries)
- evolution of water uses with impact on availability of water for irrigation
- land management and land uses changes (such as modification of the crop relative distribution , or even cropping periods)

From the agricultural point of view the objective will be to increase the water efficiency , this may mean moving to less water demanding crops, developing specific cropping patterns, including generalised drip irrigation, deficit irrigation, and more..

Among the experiments conducted by Partner 7 during the second year of the project (see individual reports section), a very interesting one has been to test the impact of the irrigation scheduling on the yield and on water saving.

The first experiment, showed that when irrigated following closely a water balance approach, olive trees have a yield increase of 50% with 24% water saving, and wheat a yield increase of 170% with 30% water saving, when compared on the average local performances (with irrigation based on availability). These very promising results will be further investigated with repetitions, whereas in a second ongoing experiment, two methods taking into account the crop water requirements of wheat are being compared : the method carried out by the ORMVAH and FAO method known as ' Dual crop coefficient approach' .

This activitiy has been pursued on the promising track developped last year adressing mainly agronomical scenarios and the related potential increase in water efficiency. However the lack of socio-economic skills has limited the efforts toward larger dimension scenarios. This WP weakness will be addressed within the frame of the connections between IRRIMED and the new project partner 1 and 7 will be involved in (PLEAIDeS)

C.2.6 WP6 End users requirements

The objective is to understand what is currently available as information on/for irrigation in the different contexts, both at the irrigation management level (farms districts, e.g.) and at the strategic level (decision making). Then from a more detailed review, this WP is meant to find out what are the expectations of the endusers in terms of information the scientists could provide, and to foster interactions with them.

During this second year, the Ministry for Water and Irrigation of Jordan (partenr 5) has been heavily involved in this WP through through three types of activites.

1. Following the first information collected during the first year from the end-users 'inside' the project, a detailed questionnaire has been established, addressing the different levels of water management:
    - Knowledge of Crop Water requirements
    - Knowledge of Irrigated Areas.
    - Availability of Meteorological Information:
    - Information Systems Incl. GIS & RS:
    - Potential End users that could benefit from the results of the Project.
    - Information needed to better manage irrigation water.
    - Issues that research need to address in order to improve efficiency of irrigation
2. This questionnaire has been sent to a panel of endusers representing a large array of situations / needs and the four MPCs countries. The results have been analysed and presented through a report on end users requirements
3. Members of the endusers panel have been invited to a one-day workshop in Amman (20 participants) to share their views , discuss the findings of the survey and to interact with the scientific team of the project (present at the occasion of the second workshop, see WP7)

The final meeting activities of this WP are planned at the end of the project to converge, and analyse what has been achieved from the endusers point of view.

C.2.7 WP7 Capacity building

This WP has been deployed through two types of activities designed by Partner1 and co-organised with all the other partners (successively) :

- the involvement of young scientists (MScs and PhDs) in each of the national teams, students under the supervision of WP leaders, they continue to contribute significantly to the project results (see publications : papers and conferences , and PhD thesis)
- the three international training workshops gathering most of theses young scientists from all project members (a full week in Palmyra, one in Amman, and one in Hammamet).

This WP had a strong inpact on building a north-south and south-south scientific spirit around the project objectives (*see management report*), and in transfering advanced high-tech know-how.

Partner 8 (ACSAD, Syria) leading in this workpackage, has been actively involved during the first workshop (hosted in Pamyra, Syria) and the final meeting, particularly through the involvment of the arabic langage science community.

C.3 Results achieved

The main scientific results are reviewed here, their potential impact is reviewed in section C5 and in the TIP document.

C.3.1 Landuse, land cover mapping

Using existing data and GIS techniques, land information systems have been build for each test site. Building on pre-existing data and information layers, the moroccan test site happened to present the largest variety of layers, whereas no preexisting data was available for the Palmyra test site. The complexity of the field patterns of this traditional oasis required to use high resolution data from the Ikonos satellite. Concerning the land use and infrastructure, the Jordan valley proved to be the most documented with GIS layers available at farm level. At the end of the day, the project test sites presented a large sampling of the different situations irrigation water manager are dealing with.

New results have been mainly obtained while working on mapping the land cover with satellite data The first striking feature has been to discover land cover is far more complex than estimated at a first guess. Two main difficulties appear :

- All fields of a given crop such as wheat do not follow the same cropping and development pattern, some fields may have been sown early , others late, some grow faster when well fertilized, and so on. As a result at a specific day all wheat fields do not have the same spectral features as captured by the satellites
- The cropping calendar can be quite complex, this is particularly true in the Jordan valley where up to 5 different crops can be grown during the season successively, leading to very intricated changing patches of land cover (vividely illustrated by the slide show of Spot satellite images posted on the project web site)

Different strategies have been used to overcome these obstacles. Temporal profiles of vegetation indices are often insufficient to distinguish among annual crops, but have proven to allow to discriminate the main land cover classes (in the case study of the Haouz plain, Morocco) (Simonneaux et al., 2003, 2007). An interesting result is the refinement of the approach achieved through combination between this map and other data sources. We thereby overlaid a map of trees plantations obtained by analysis of very high resolution images (SPOT 2.5m Panchromatic) using the Olicount software (©ISPRA) to improve the delineation of plantations. This is a valuable information as trees are rather stable over years and require specific processing regarding irrigation assessment.

C.3.2 Micrometeorological measurements

C.3.2.1 Assessment of actual Evapotranspiration (ET)

C.3.2.1.1 Measurments in the Jordan Valley

In these experiments the actual evapotranspiration was measured by partner 4 (NCARTT) using the eddy-correlation (EC) system. Partner 2 (H.de Bruin and O.Hartogensis) assisted with installation of the EC-equipment and provided training

The **alfalfa** site was located in the University of Jordan experimental farm at N 32^o 05' 21.4 and E 35^o 35' 46.7.. From the EC- data the crop factor, K_c, was evaluated. These were compared with the values given by FAO for alfalfa. In general, the EC values appears to be lower than the FAO ones.

This **tomato** crop site was located at N 32^o 11' 25.6", E 35^o 37' 2.1'', in the experimental station of NCARTT.The EC measurements of actual evapotranspiration (ET) were collected form 28 January - June 15 2004. Crop data were collected weekly. Crop-reference evapotranspiration (ET0) were obtained from a nearby automatic weather station of NCARTT. Total measured ET for tomatoes was 346mm, whereas the crop water-requirements according to FAO was 543 mm.

The total measured actual ET_C for **sweet corn** was 274mm, whereas the estimated added irrigated water was 430 mm. The evaluated K_C values for sweet corn appeared to be smaller than the FAO-K_C values.

The area of this **potato** crop field was about 2.0 ha and was planted with 14th -21st December 2004. The crop was harvested on 18th May 2005. The experimental set-up was the same as for the crops described previously. The total measured ET for Potato in this experiment was 252mm. The amount of water added to the field was about 370mm. Note that during this winter season the crop did not suffer from water stress.

The same field was planted with **cauliflower** crop at the beginning of November (4 November 2005). The experimental set-up was similar to the previous experiment. The crop was harvested on 23 March 2006. The total ET for Cauliflower crop measured in this experiment was 178mm. The amounts water supplied to the field was 245mm.

C.3.2.1.2 Measurements in Syria

The **Palmyra oasis** is located near the town of Palmyra (34^o 32´ N, 38 ^{o} 16´ E) in the center of the Syrian Desert (see report of partner 8). EC-measurements of ET have been collected over in a 0.4 ha field with fetch of 1 km in all directions, using a CR23 X data logger. Information of soil moisture was gathered up to a depth of 1.5m, using TDR, tensiometers and a CR10X data logger and analysed by Drs. Ihab Jnad, Abdullah Droubi and Jean Pierre Brunel (partner 8). They evaluated ET0 using the formulas of FAO, Turc and Hargeaves. They evaluated crop factors for this mixed crop oasis for soil moisture data and compared these with values given in literature. The checked the energy-balance closure of the EC data and found that the sum of EC sensible and latent heat is about 90% of the measured net radiation minus soil heat flux. The daily measured actual evapotranspiration was lower than the crop water requirements according different formulas, with the smallest differences between EC and Turc. Using stress factor derived from soil moisture data and EC, a much better agreement was obtained, where the Turc method gave the best fit.

The **Sabkht Al Mouh Desert-**site near Palmyra concerns bare soils with an area of 16,000 km^2. The groundwater level ranges between 0.2 and 1m below soil surface. In 2004 and 2005 the sensible heat flux was determined using a simplified flux-profile method (measurements at two levels of temperature and wind speed). Next, actual evapotranspiration was evaluated from the surface energy balance equation, using measurements of net radiation and soil heat flux. These values were compared with isotopic observations done earlier.

C.3.2.1.3 Kamech catchment site, Tunisia

This field experiment concerns a small hydrological watershed named Kamach. It is located in the Cap Bon region, Tunisia and has an area of in 2,45 km^2. The agricultural fields are small and the terrain is inclining. Some slopes are 20%. The hydro-meteorological data are collected since 1994. INRGREF (partner 9) carried out a study where actual evapotranspiration data gathered over selected fields with EC or Bowen ratio method are used to calibrate a soil-vegetation-atmosphere-transfer (SVAT) model. In its turn, this model will be used to determine ET for the whole catchment. A long-path large aperture scintillometer is used to validate the latter. The Eddy covariance data were collected (using a CR23X data logger) over a wheat field, bare soil and ploughed soil in 2004 (04/2004 to 12/2004) and an oat crop between 18 January 2005 and 24 May 2005, followed by barley (orge) and faba beans (fève) in 2006. All fields have one flat side with 7% slope and one complex topography side. Primarily results suggest that the planar fit correction method, which accounts for terrain slopes, give good results for the moderately inclined field side whereas there are indications that for the complex field side, unrealistic mean vertical wind speeds are found after planar fit corrections. The research is still in progress.

C.3.2.1.4 Measurements in Morocco

The **Saâda orange orchard** is located 15 km from Marrakech, Morocco. Tree spacing is 7 m and the tree height and width was 3.25 m 3.75 m respectively. The objective of the experiment was to study heterogeneity of the energy balance for this sparse, tall vegetation type. A 9 m tall tower was installed with standard meteorological measurements, eddy correlation instruments and hemispherical radiometers. Soil heat flux plates were installed under the trees, patches of sparse grass, and bare soil points. TDR soil moisture probes have been installed at one location, together with gravimetric measurements. IR-thermometers were installed around 2 trees pointing in different directions and monitoring shaded and sunlit sides, above the grass, the shaded soil and the sunlit soil. Surface soil moisture variability was measured during an intensive observation period using capacitance probes.

R3 site is about 45 km East of Marrakech and was instrumented by a set of standard meteorological instruments to measure wind speed and direction, air temperature and humidity, net radiation, surface and soil temperatures and sol heat flux and moisture. The average sensible and latent heat fluxes were measured by using two techniques: the Scintillation method (2 large aperture scintillometers were installed over a path of

1.5km) and an Eddy-covariance system. The Large aperture scintillometer provides fluxes at regional scale while the eddy-covariance restraint to the field scale. The path of the two scintillometers covers a mixed field of olive and wheat. The Eddy-covariance system was installed over olive trees and still running until now. The general objective of this experiment was to analyze the potential of the FORMOSAT-2 time series of images to monitor the regional land-use/land-cover, water balance and crop yield in the semi-arid regions. For this reason a times series of FORMOSAT-2 images has been acquired over the Al Haouz/Marrakech plain, from November 2005 to now with a time step of 4 days.

The **Orange tree test site at Agafay** is located at 50 km south-west of Marrakech and it concerns orange trees with drip irrigation. The objectives of this experiment are (i) To examine the evolution of the fluxes over the period study and the partitioning of available energy into evapotranspiration and sensible heat flux at a vegetation surface using sap flow measurements, (ii) To monitor the water consumption by the orange using the eddy covariance system and the FOA-56 model.

C.3.2.2 Reference-crop evapotranspiration ET0

We recall that ET0 is defined through the FAO-relationship ETC = K_C ET0, where ET0 is the reference-crop evapotranspiration that refers to the evapotranspiration of a hypothetical stress-free extensive grass field having a prescribed albedo and roughness length. Moreover, ET0 is evaluated with a special version of the Penman-Monteith equation requiring the incoming solar radiation, air temperature, humidity and wind speed measured over well-watered grass. During the IRRIMED project new ET0 stations were installed. Moreover, a start is made with a study on the question whether ET0 can be obtained from satellites images.

Maintenance of ET0 stations is costly and requires well-trained staff. In particular in semi-arid countries it is difficult to grow and maintain well-watered grass according to the FAO definition. Consequently, the number of high quality ET0-stations is small, in particular in those countries where water is scarce and food production highly depends on irrigation. Several studies, have revealed that a simple radiation based method can provide reliable ET0 estimates. Besides the air temperature, these equations require either the incoming shortwave radiation or net radiation. Recently, incoming solar radiation derived from MSG satellite became available for most regions around the Mediterranean.

C.3.2.3 Novel methods to measure actual evapotranspiration

The main objective of the IRRIMED project was transfer of existing knowledge. Nonetheless, in the context of IRRIMED some studies were done on the applicability of novel techniques to determine actual evapotranspiration (ET). This concerns the scintillometry and stable isotope and sap flow methods.

C.3.2.3.1 Large Aperture Scintillometers (LAS)

A large-aperture scintillometer is an optical instrument consisting of a transmitter and receiver that measures the intensity fluctuations, expressed as the variance of logarithm of the intensity of the transmitted light-beam along the line of sight. This variance is related to the sensible heat flux averaged over the path length. The latter can vary between 500m to 10 km. different LAS experiments have been carried in Morocco.

- **LAS experiment at the Agdal olive tree site, Morocco**

FSS, IRD and WU tested the applicability of a Large Aperture Scintillometer (LAS) over an olive tree plantation in the gardens of Agdal, Marrakech, Morocco. The seasonal water consumption was determined with a LAS combined with a simple available energy model. Comparisons were made with eddy correlation. The advantage of a LAS over eddy correlation is that the footprint of the LAS is much larger. This is an advantage due to the flood irrigation method used in the site, which induces irregular pattern of soil moisture. It is concluded that the LAS can be considered as a potentially useful tool to monitor the water consumption in complex conditions. A paper has been accepted for publication. More information can be found in the report by FSS, IRD and WU.

- **LAS experiment at the R3-site, Morocco**

In 2005-2006 at a site named R3 located at ca 45 km East of Marrakech a LAS experiment was performed. Two LAS were deployed over a mixed olive-trees and wheat with the objective to analyze the potential of the FORMOSAT-2 time series of images to monitor the regional land-use/land-cover, water balance and crop yield in the semi-arid regions.

C.3.2.3.2 eXtra Large Aperture Scintillometer (XLAS)

In collaboration with IRD, WU installed a XLAS at a site south of Toulouse, France. The LAS described above has an aperture diameter 0.15 m, and can be operated over a path length of up to 5 km. The XLAS has an aperture of 0.3 m and can be used over a path length of about 10 km. The XLAS experiment ran between 25 June 2005 to 25 March 2006 and yielded good data between July 2005 and January 2006. The XLAS was set-up between the villages Muret and Lherm over a path-length of 9.6 km and at a height of approximately 45 m. Recent research has shown that for path lengths of about 10 km a correction for saturation has to be applied. We developed for the set-up near Toulouse a simplified saturation correction procedure that can be applied by non-experts on scintillometer theory also.

C.3.2.3.3 Short-path scintillometers over irrigated field under advective conditions

In the context of IRRIMED WU studied agro-hydrological scintillometer applications of estimating actual evapotranspiration (ET) over homogeneous irrigated alfalfa field in Idaho, under conditions where advection causes negative sensible heat flux the entire day. Two types of scintillometers were considered, notably a displaced beam small aperture laser scintillometer and the large aperture scintillometer (LAS). The data were collected during the the RAPID (Regional Advection Perturbations in an Irrigated Desert) field experiment in Idaho, USA in 1999. The scintillometer data were not analyzed before. It was concluded that both scintillometer systems, in combination with net radiation and soil heat flux measurements, are useful to estimate operationally evapotranspiration also under advective conditions. Advantages of the scintillometer over the EC-method are that scintillometers are robust and simple to operate, the scintillometer components can be installed at the border a field avoiding interference with the farmer’s activities, and the scintillometer footprint is better defined than that of EC measurements..

C.3.3 Development of reference and simplified SVAT models

C.3.3.1 Implementation of the different SVAT models (olive and wheat fields)

Implementing and testing the different Soil Vegetation Atmosphere Transfert models allowed to evaluate their performance and benefits. The *FAO56* dual-coefficient as been applied to three wheat sites (B123, B130 and B27) and the olive site. It overestimates the soil evaporation, especially for the Agdal/Olive site, but as well for the wheat. The temporal dynamics of each component (soil evaporation and transpiration) seems to be well represented, but the relative contribution of each component on the total evaporation seems to be unbalanced in favour of the soil contribution, especially just after the rain or an irrigation event (Er-raki et al., 2007)

As expected, *SVATsimple* performs well at the wheat site, compared to *SiSPAT* (Table 1) and reasonably well (given its simplicity) at the olive site. SiSPAT is calibrated manually, whereas SVATsimple is calibrated with an automatic simplex method.

OLIVE (Agdal)	SVATsimple			SISPAT		
	E	RMSE	B	E	RMSE	B
Rn before	0.9	68.8	39	0.87	76.0	17.5
Rn after	0.92	60.5	36	0.92	67.0	21
LE before	0.70	59	26	0.78	51.1	6.2
LE after	0.77	51	6.9	0.91	31.5	7.3
H before	0.78	44.68	-9.52	0.71	51.6	-28.1
H after	0.82	42.4	1.64	0.80	52.0	-6.37
Trad before	0.66	5.2	-0.76	0.85	5.29	-5.5
Trad after	0.67	4.5	-0.51	0.92	3.4	-1.10

WHEAT (B123)	SVATsimple			SISPAT		
	E	RMSE	B	E	RMSE	B
Rn before	0.91	42	14.3	0.91	23.4	27.3
Rn after	0.96	25.1	17	0.99	21.3	22.5
LE before	0.71	38.5	15.2	0.81	32	29.4
LE after	0.87	24.2	7.9	0.94	23	17.5
H before	0.71	37	-12	0.67	66	35.2
H after	0.89	32	-8.5	0.7	43.6	25.7
Trad before	0.82	4.6	-5.2	0.84	4.7	-4.12
Trad after	0.94	3.1	-0.52	0.99	2.1	-3.1

Table 1: performance statistics before and after calibration of *SVATsimple* and *SiSPAT*
(Rn net radiation, LE latent heat flux, H sensible heat flux, in W/m^2, Trad radiative surface temperature, in °C)

SVATsimple has also been applied to the Tunisian site with satisfying results as well. Problems with some of the micrometeorological conditions (fetch requirements and small number of heat flux plates used) explain most of the discrepancies between the model and the observations. In particular, the decrease in soil heat flux G at the end of the season is not in agreement with the fact that vegetation is senescent and soil is almost bare. Mulching could be responsible for that. Observed latent heat flux LE, as a result, seems overestimated at that time (it is computed as a residual of the energy balance) while sensible heat flux H and net radiation Rn are more realistic and agree with the models outputs.

C.3.3.2 Selected scientific avenues within WP3

C.3.3.2.1 SVATsimple versus SiSPAT model intercomparison

As said in introduction, for a regional assessment of water needs and consumption in semi-arid agricultural zones, one needs robust and simple tools that provide space-time estimates of evaporation losses. Most operational evaporation estimates rely on semi-empirical relationships that are not generally applicable (e.g. the FAO56 method). Several authors have proposed physically-based simple expressions to model the "energy-limited" (stage one) and the "supply-limited" (stage two) evaporation rates during a dry down. A full analytical solution has been developed and used to build a simple yet physically-based SVAT model, SVATsimple. The derived "supply-limited" evaporation rate is evaluated for a wide range of soil conditions and vegetation cover against the complex physically based Soil-Vegetation-Atmosphere Transfer model, SiSPAT. SiSPAT solves the differential equations of water flow in a vertical soil column and computes estimates of soil evaporation and transpiration. The full analytical solution gives accurate predictions of first to second-stage evaporation time series for the bare soil and vegetated cover conditions with a Leaf Area Index of 3 or higher. The results of the full solution are closer to the evaporation rate time series simulated by SISPAT than the asymptotic approximations (Boulet et al., 2004).

C.3.3.2.2 Use of Thermal Infra Red remote sensing to detect second-stage evaporation processes and retrieve soil moisture status

TIR data can be used to detect water stress by plotting classically the Water Deficit Index or WDI (Moran et al., 1994). WDI is a function of the unstressed (T_{sp}) and stressed (T_{s0}) temperatures:

$$WDI = \frac{T_s - T_{sp}}{T_{s0} - T_{sp}} \cong 1 - \frac{e}{e_p} \qquad (1)$$

Where T_s is the observed surface temperature derived from TIR data, e is the actual evaporation rate, and e_p is the evaporation rate in potential conditions. However, the WDI relies on the estimation of both unstressed and fully stressed surface temperatures, which are the equilibrium temperatures of a given surface expressed in potential conditions and for no evaporation (respectively). These temperatures are computed with an energy balance model. Given the uncertainties on stability corrections and soil heat flux values, the stressed temperature T_{s0} is difficult to compute. We've shown that using solely the difference between the actual and the unstressed surface temperature as a baseline to monitor water stress is very efficient.

This has been illustrated within the frame of IRRIMED: in most cases, the difference between the observed and the unstressed surface temperatures is almost linearly related to water stress, which means that the denominator of the WDI is rather superfluous for stress detection. Even with inaccurate but realistic values of the surface parameters used to solve the energy balance and compute the unstressed temperature, we found that the observed to unstressed surface temperature difference is still more relevant to detect second-stage processes than the difference between the observed surface temperature and the air temperature, also used classically to detect hydric stress (Boulet et al., 2007).

C.3.3.2.3 Soil/Plant energy partition

Evaluation of evaporation estimation methods to compute irrigation requirements is usually based on assessing model performance in computing total latent heat flux. However, improving water use efficiency for most irrigation practices means that bare soil evaporation is reduced while transpiration is maximized. This implies that model performance must be assessed for the evaporation components rather than the total. Directional surface temperature measurement could be a mean to evaluate how the model partitions the available energy into transpiration and soil evaporation. Prior to assimilating the remotely sensed directional temperatures, we must check that the surface temperatures simulated by the selected Soil-Vegetation-Atmosphere Transfer model for the different vegetation surfaces (shaded and sunlit bare soil, shaded and sunlit leaves) match the remotely sensed observed temperatures of these individual components.

In order to check whether the SVAT model ICARE has the adequate description of the energy and water budget components in the case of semi-arid sparse vegetation stands, an experimental set-up was designed and installed at the Saada2 orange orchard. Saada2 is an interesting dataset to describe the heterogeneity of the water and energy budgets for most sparse semi-arid orchards under flood irrigation. Since ICARE is originally a 1 compartment model with two interacting sources of heat, i.e. that the vegetation is a semi-transparent layer overlaying the soil, it might not be adapted to describing the mass and energy exchange of a sparse canopy. A 3 compartment version of ICARE has been built to provide a more realistic description of the Saada2 system. It assumes, like the side-by-side versions of SVATsimple or the dual-crop FAO56 method, that the variability of the energy exchange can be represented by three independent columns: one of unshaded bare soil, one of short vegetation, and one of tree overlaying the shaded soil.

It was shown that the variability of the energy balance is reasonably well reproduced by the 3 compartments ICARE, while the 1 compartment ICARE provides a realistic average energy balance. Modifications of the 1 compartment ICARE model to take into account the sparse canopy energy exchange have been proposed (Boulet et al., 2006) by building an empirical relationship between the surface temperatures computed with the 1 compartment model and that of the 3 compartment model. This empirical relationship can be seen as an “observation model” priori to directional TIR data assimilation (Boulet et al., 2006).

C.3.4 "spatialisation": simple models applied to satellite images

In order to integrate ETR simplified model into GIS (land cover, soil/meteo), an important effort was paid within two directions: 1) link of optical remote sensing data with biophysical data for the characterisation of crop development stages and evapotranspiration; 2) test/development of crop models for the monitoring of the vegetation dynamics and crop coefficients. The main results have been obtained on the Moroccan test site.

1) Optical data acquired at surface (handheld radiometer) and from space (Landsat images) were analysed together with actual evapotranspiration (AET) collected at field (see WP2). The analysis allowed to establish relationships between the Normalised Difference Vegetation Index (NDVI), the Green Leaf Area Index (GLAI) and plant maximal transpiration (Duchemin et al. 2006). These relationships were used to set-up the FAO-56 method and the gain in accuracy resulting from the use of remote sensing data was evaluated (ErRaki et al. 2007).

2) The SAFY model ('Simple Algorithm For Yield estimates') was specifically developed to represent well-known processes involved in crop development and growth, with the requirement that these processes can be simulated using standard data, i.e. climatic data and optical imagery (which provides estimates of leaf area index). Based on the work of Monteith (1965) and Maas (1993), the SAFY model includes three subsets of equations to simulate the time courses of the dry above-ground mass, and the green leaf area index and grain yield. The model was evaluated against data collected on irrigated wheat crops on the moroccan test site during two successive agricultural seasons : 2002/2003 (used for calibration) and 2003/2004 (used for validation).

This validation evidenced very satisfying performances for the SAFY model (Duchemin et al. 2005, 2007a). In parallel, the STICS model of INRA-France was tested on the same experimental conditions (Hadria et al. 2006, 2007). After calibration, the model was used to: a) analyse the productivity of wheat crops for various management practices in terms of sowing and irrigation; b) test the accuracy of AET estimates under various conditions of data acquisition. This model was not retained in the context of spatialisation since there is a too large number of model parameters and input data (and especially data related to crop management practices).

The SAFY model has been successfully used with satellite imagery over the R3 wheat test site in Morocco. At a regional scale, our research has mainly focused on the use of time series of high spatial resolution images for the mapping of land classes as well as for the follow up of vegetation characteristics and water use. The method we developed are based on the driving of a simple Evapotranspiration model adapted from the FAO-56 method. The method was tested using two time series of high spatial resolution images acquired by Landsat-TM during the 2002-2003 agricultural season (Simonneaux et al. 2007)and by FORMOSAT-2/RSI during the 2005-2006 agricultural season (Duchemin et al. 2007b). It provides with digital map of crop water needs, actual evapotranspiration and irrigation water requirements at different space and time scales (WP4 deliverables 1, 3 and 4). Their interest for optimising water resource (WP4 deliverable 2) was tested for irrigated wheat in the Marrakech plain. These methods were incorporated into the SAMIR

(SAtellite Monitoring of IRrigation) tool which was developed together by IRD (partner 1), ORMVAH (partner 7) and UCAM (partner 6, *see the respective individual reports*).

C.3.4.1 SAMIR and the concept of “Intermediate Evapotranspiration”

Whereas the remote sensely based approach used in SAMIR is providing spatially distributed evapotranspiration (ET) values, it is based on the requirements (KCs) adjusted to the actual crop development (instead of potential, when using only the FAO values « from the book »). However it does not take into account the actual water availability for the plants, so it is not the actual ET as crops may be stressed without this being noticed from space thorugh the NDVI (which is not immediately decreasing when a crop is water stressed).

Therefore we have introduced the concept with satellite we are in fact computing a spatially distributed evapotranspiration, whose values are somehow intermediate between the potential one (well watered fully developped crop) and the actual one (as illustraded in the next figure).

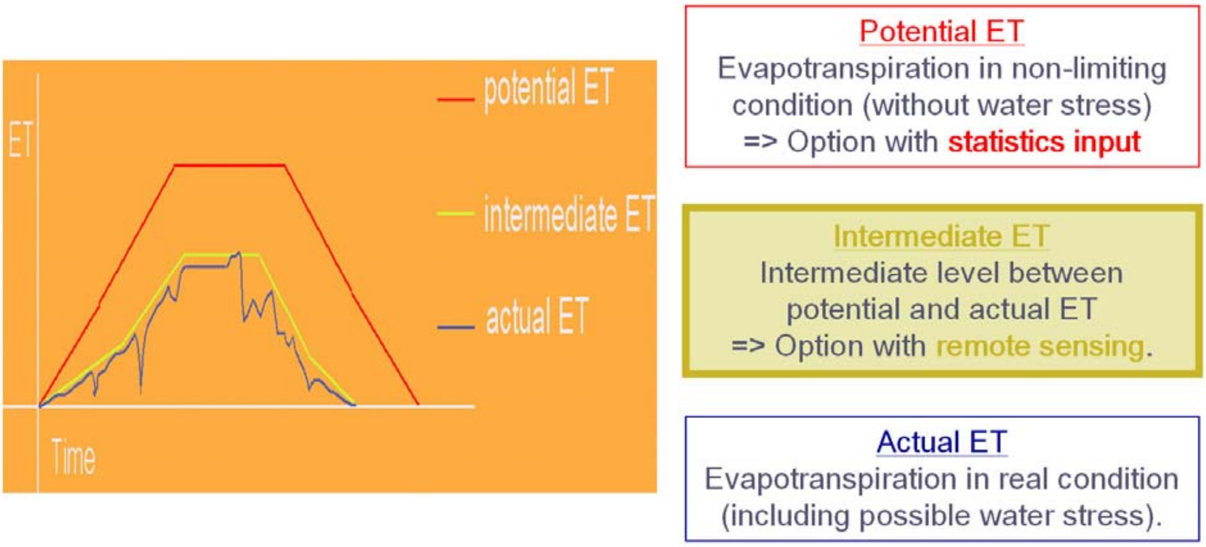

Fig 3 Evapo-transpiration monitored with remote sensing compared to the usual concepts

When considering the results obtained, from a **scientific** point of view the development of SAMIR allows to explore and compare the possibilities of spatialized ET estimations, using various data sets / qualities, **focusing on remote sensing capabilities**

- **of various resolutions :**
  - From global knowledge (by sectors)
  - To plot level (if high resolution satellite data available)
- **of various time frequency**
  - Global spatialisation : potentially daily (low resolution)
  - High resolution images : every 3 weeks seems reasonable
  - Weekly using new (FORMOSAT) or future missions (Venus / GMES)

On the **operational** side SAMIR demonstrate to the End-Users the possibilities of **water budget monitoring**, while interacting with them to taylor it to their needs, as it has been done during this project

As it is an evolutive tool, likely to be adapted to various irrigated sites, it will be further developped within the frame of new project (see comments on PLEIADeS).

C.4 Problems

Following the readjustments discussed during the second year meeting, the science plan has unfolded very satisfactorily, following the new time table. Activities bridging the scientific team and the end users community have been rescheduled towards the end of the project, to allow to present the final methodology. Field experiments in Jordan and in Morocco delayed during the second year have been fully developed. In short after relaxing the experimental plan, all teams managed to fulfil their experimental plans and even beyond.

C.5 Technology implementation plan

The technology implementation plan is formally developed in the appropriate separate document.

However, the general question of an implementation plan has been addressed from the beginning by a fully dedicated workpackage. The objective being to involve the endusers (mainly water and irrigation district managers) into the project really enough to ensure their requirements will be taken into account and the project will avoid the pitfalls of designing scientifically attractive solutions but of poor potential impact.

The results of these activities lead by partner 5 (MWI, Jordan) are detailed in the corresponding individual report and particularly its annexes. Two major end-users requirement have emerged of the discussions and should be addressed in the implementation plan:

1. Identification of Irrigated Areas & Estimation of Cropped Areas:

The allocation of water by irrigation management institution is done on the basis of the actual area of irrigated crops, and not on the area of farms or potential irrigated area. Thus the knowledge of the actual areas of crops at various times of the year is a basic requirement of all end users. The identification of the main species regarding irrigation (e.g. trees and annual crops, and possibly more details) is also requested. This information about land cover is all the more important as the statistics available from farmers' declarations or ground survey are not considered reliable by the managers.

2. Improved Knowledge of Crops Water Requirements:

Since water allocation is done on equal share basis per hectare (e.g. in Morocco), or based on quotas assigned for main crop categories (i.e. in Jordan), the knowledge of actual crop development is not a priority for the irrigation distribution, but more for seasonal forecasting. Farmers could also benefit from such information as they need to know as accurately as possible the water needs to minimize the input he usually has to complement. One other use of accurate water requirement assessment offered by satellite image time series at the global level is the estimation of pumping, assuming the difference between observed needs and institutional inputs is coming from ground pumping.

From the technological point of view, the methods developed have been indeed following these main requirements :

- Assessing the irrigation and crop extent, through the use of satellite data combined in multitemporal sets:

the performance of different resolutions and classification techniques have been evaluated, and can be used as a criteria for implementation according to the size of the area to monitor, skills available and objectives of the users

- Better assessment of Crop water requirements in the field and their spatialization with satellite data :

The micrometeorological measurements techniques used, Eddy Covariance (at field level) and Scintillometry (at fields bloc level) have proven their performance and usefulness (large difference between estimated and actual evapotranspiration). Moreover a strategy for their combined used has been tested and will be a key element of any ground micromet measurement implementation plan.

The remote sensing development part has been implemented in a software prototype called SAMIR (for SAtellite Monitoring of Irrigation). The computer code of this prototype has been written in the language used for the other project remote sensing applications (IDL from RSI).

For this reason it is not yet a fully portable application but it has raised signification interest outside the project, both for further development in the southern countries context within a new EC funded project (PLEAIDeS, see conclusion) and for the new regional agricultural monitoring project in SW of France (OSR, Toulouse, leader CESBIO).

The next step of the implementation will be deployed within these new undergoing projects, with two major enhancements towards a wider use:

- Better portability: use of a non proprietary (generic) computer code, easy to access and tailor to different users needs
- Better access: the application will be implemented in web server to allow users to access it directly through the internet (for the public part, access rights will be implemented for specific data)

SMEs are involved in this phase for the second project (in France) and might develop their own products out of it. However in the context of the scientific collaboration with Southern Countries, which is the mandate of IRD, CESBIO (one of its research labs) will continue to develop with these partners open source (royalties free) applications.

C.6 Publications and papers

Among the publications of the project, it can be first emphasized that during its life time **9 PhD thesis** have been defended:

ABOURIDA, A. (2007). Approche hydrogéologique de la nappe du Haouz (Maroc) par télédétection, isotopie, SIG et modélisation. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad (Morocco) , 196 p.

CHAPONNIÈRE A.(2005) Fonctionnement hydrologique d'un bassin versant montagneux semi aride. Cas du bassin versant du Rehraya (Haut Atlas marocain) Institut National Agronomique de Paris Grignon, 268 p.

ER-RAKI, S. (2007). Estimation des besoins en eau des cultures dans la région de Tensift AL Haouz : Modélisation, Expérimentation et Télédétection. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad (Morocco), 128 p.

EZZAHAR, J. (2007). Spatialisation des flux d'énergie et de masse à l'interface Biosphère-Atmosphère dans les régions semi-arides en utilisant la méthode de scintillation. *UFR : Thermique et Mécanique des Fluides*. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad. (Morocco), 115 p.

HADRIA, R. (2006). Adaptation et spatialisation du modèle STICS pour la gestion d'un périmètre céréalier irrigué en milieux semi aride. Marrakech, Maroc, Faculté des Sciences Semlalia, Université Cadi Ayyad (Morocco). , 216 p.

HARTOGENSIS, O. (2006). Exploring Scintillometry in the Stable Atmospheric Surface Layer. Wageningen, Netherlands, Wageningen University, 240 p.

HOEDJES, J. (2007). Estimation de l’Evapotranspiration sur des Surfaces Irriguées en Zones Semi-arides : Combinaison Modélisation, Télédétection et Scintillométrie. Toulouse, France, Université Paul Sabatier (UPS), 167 p.

JITAN, M. (2005). Evapotranspiration of major crops in the Jordan Valley using Remote Sensing techniques compared with estimated field measurement using Eddy-Correlation. Thèse, University of Jordan, Amman, Jordan, 235 p.

MERLIN O. (2005) Synergie des observations multispectrales : Application en hydrologie. Spécialité Télédection et Hydrologie. Université Paul Sabatier - Toulouse-III. 152 p.

The full set of publications listed here below has been made available through the project website. The ‘project library’ page offers queries to select, then download the numerous papers and reports in acrobat format All project publications are listed here after in chronological order.

2007

Baret, F., Weiss, M., Allard, D., Garrigue, S., Leroy, M., Jeanjean, H., Fernandes, R., Myneni, R., Privette, J., Morisette, J., Bohbot, H., Bosseno, R., Dedieu, G., Di-Bella, C., Duchemin, B., Espana, M., Gond, V., Gu, X., Guyon, D., Lelong, C., Maisongrande, P., Mougin, E., Nilson, T., Veroustraete, F., and Vintilla, R. (?). VALERI: a network of sites and a methodology for the validation of medium spatial resolution land satellite products. *Remote Sensing of Environment*, in press.

Boulet, G., Chehbouni, A., Gentine, P., Duchemin, B., Ezzahar, J., and Hadria, R. (2007). Monitoring water stress using time series of observed to unstressed surface temperature difference. *Agricultural and Forest Meteorology*, in press.

Duchemin, B., Leroux, J., Boulet, G., Maisongrande, P., Hanich, L., Boudhar, A., Chaponnière, A., and Chehbouni, A. (2007). Improvement of remotely sensed snow cover monitoring in semi-arid High Atlas mountains and its assimilation in a distributed hydrological model. *In* "General Assembly of European Geosciences Union (EGU)", Vol. 9, pp. 08129, Vienna, Austria.

Er-Raki, S., Chehbouni, A., Guemouria, N., Duchemin, B., Ezzahar, J., and Hadria, R. (2007). Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region. *Agricultural Water Management* **87**, 41-54.

Ezzahar, J., Chehbouni, A., Hoedjes, J., and Chehbouni, A. (2007). On the application of scintillometry over heterogeneous grids. *Journal of Hydrology* **334**, 493-501.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Er-Raki, S., Chehbouni, A., Boulet, G., Bonnefond, J., and De-Bruin, H. (2007). The use of the scintillation technique for monitoring seasonal water consumption of olive orchards in a semi-arid region. *Agricultural Water Management* **89**, 173-184.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Er-Raki, S., Duchemin, B., and Chehbouni, A. (2007). The use of the Scintillation Technique for estimating evapotranspiration ET over several agricultural fields in semi-arid region. *Plant Biosystems*, submitted.

Hadria, R., Duchemin, B., Khabba, S., Lahrouni, A., Benhadj, I., Olioso, A., and Chehbouni, A. (2007). Utilisation du modèle STICS pour la conduite optimale de cultures céréalières en région aride (plaine de Marrakech/Al Haouz). *In* "Troisième séminaire STICS", pp. 25-28, Reims, France.

Hadria, R., Khabba, S., Lahrouni, A., Duchemin, B., Chehbouni, A., and Carriou, J. (2007). Calibration and Validation of the STICS Crop Model for Managing Wheat Irrigation in the Semi-Arid Marrakech/Al Haouz Plain. *Arabian Journal for Science and Engineering* **32**, 87-101.

Hadria, R., Olioso, A., Duchemin, B., Ruget, F., Weiss, M., Rivalland, V., Guérif, M., Lahrouni, A., and Lecharpentier, P. (2007). Couplage du modèle STICS et de données de télédétection optique pour la détermination des pratiques culturales en région des Alpilles. *In* "Troisième séminaire STICS", pp. 25-28, Reims, France.

Simonneaux, V., Duchemin, B., Helson, D., Er-Raki, S., Olioso, A., and Chehbouni, A. (2007). The use of high-resolution image time series for crop classification and evapotranspiration estimate over an irrigated area in central Morocco. *International Journal of Remote Sensing*, in press.

2006

Boulet, G., Chehbouni, A., and Gentine, P. (2006). On the use of the surface temperature in potential conditions to monitor water stress together with TIR data. *In* "2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II)" (J. Sobrino, ed.), pp. 421-425. Publicacions de la Universitat de València, Valencia, Spain.

Chehbouni, A., and Foutch, G. (2006). Recycling saltwater for irrigation in Marrakech region. *In* "Gestion Intégrée des Ressources en Eaux et Défis du Développement Durable (GIRE3D)", pp. 6, Faculté des Sciences Semlalia, Marrakech, Maroc.

Duchemin, B., Hadria, R., Er-Raki, S., Boulet, G., Maisongrande, P., Chehbouni, A., Escadafal, R., Ezzahar, J., Hoedjes, J., Kharrou, M., Khabba, S., Mougenot, B., Olioso, A., Rodriguez, J.-C., and Simonneaux, V. (2006). Monitoring wheat phenology and irrigation in Central Morocco : on the use of relationship between evapotranspiration, crops coefficients, leaf area index and remotely-sensed vegetation indices. *Agricultural Water Management* **79**, 1-27.

Er-Raki, S., Chehbouni, A., Guemouria, N., Duchemin, B., Ezzahar, J., and Hadria, R. (2006). Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region. *Agricultural Water Management* **87**, 41-54.

Er-Raki, S., Chehbouni, A., Guemouria, N., Duchemin, B., Ezzahar, J., Hadria, R., and Benhadj, I. (2006). Driven FAO-56 dual crop coefficient approach with remotely-sensed data for estimating water consumption of wheat crops in a semi-arid region. *In* "2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II)" (J. Sobrino, ed.), pp. 431-436. Publicacions de la Universitat de València, Valencia, Spain.

Er-Raki, S., G.Chehbouni, N.Guemouria, J.Ezzahar, R.Hadria, Duchemin, B., Boulet, G., and Chehbouni, A. (2006). Developing crop coefficients for olive, wheat and orange growing in semi arid region (Marrakech, Morocco). *In* "Gestion Intégrée des Ressources en Eaux et Défis du Développement Durable (GIRE3D)", pp. 8, Faculté des Sciences Semlalia, Marrakech, Maroc.

Er-Raki, S., Guemouria, N., Chehbouni, G., Ezzahar, J., Hadria, R., and Chehbouni, A. (2006). Assesing water cunsumption of olive orchards in a semi arid region (Marrakech, Morocco). *In* "1er Congrès national sur l'Amélioration de la Production Agricole (APA)", pp. 1-8, Settat, Maroc.

Er-Raki, S., Guemouria, N., Chehbouni, G., Fachtali, B., Ezzahar, J., Hadria, R., and Chehbouni, A. (2006). Measurement and modelling evapotranspiration of irrigated citrus orchard under drip and flood irrigations. *In* "3rd International Conference on Water Resources in Mediterranean basin: WATMED 3", pp. CD-ROM, Tripoli, Lebanon.

Escadafal, R. (2006). "IRRIMED : Improved management tools for water-limited irrigation: combining ground and satellite information through models - Annual Report Year III covering period from April 1st 2005 to March 31 2006." European Commission INCO-DC : International Cooperation with Developing Countries.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Er-Raki, S., Chehbouni, A., and Hadria, R. (2006). Seasonal variation in evapotranspiration, sensible heat flux and energy balance in olive orchard under traditional irrigation. *In* "Gestion Intégrée des Ressources en Eaux et Défis du Développement Durable (GIRE3D)", pp. 7, Faculté des Sciences Semlalia, Marrakech, Maroc.

Hadria, R., Duchemin, B., Lahrouni, A., Khabba, S., Er-Raki, S., Dedieu, G., Chehbouni, A., and Olioso, A. (2006). Monitoring of irrigated wheat in a semi-arid climate using crop modelling and remote sensing data : Impact of satellite revisit time frequency. *International Journal of Remote Sensing* **27**, 1093–1117.

Hadria, R., Lahrouni, A., Duchemin, B., Khabba, S., Ezzahar, J., Er-Raki, S., Chehbouni, A., Olioso, A., and Dedieu, G. (2006). Contribution de la modélisation à la gestion d'eau d'irrigation en milieux semi-arides. *In* "1er congrès national sur L'Amélioration de la Production Agricole (APA)", pp. 1, Settat, Maroc.

Hadria, R., Olioso, A., Duchemin, B., Ruget, F., Weiss, M., Rivalland, V., Guérif, M., Lahrouni, A., Chehbouni, A., and Lecharpentier, P. (2006). Spatialization of sowing date and nitrogen supplies by combining remote sensed leaf area index and a crop simulation model. The case of durum wheat in the Alpilles test area (South-East of France). *In* "2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II)" (J. Sobrino, ed.), pp. 369-374. Publicacions de la Universitat de València, Valencia, Spain.

Maisongrande, P., Lobo, A., Lattes, P., Duchemin, B., Gouaux, P., Rosnay, P. d., Ceschia, E., and Dedieu, G. (2006). Multiresolution caracterisation of the vegetation water stress on the basis of shortwave vegetation indices. *In* "2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II)" (J. Sobrino, ed.), pp. 397-401. Publicacions de la Universitat de València, Valencia, Spain.

Merlin, O., Chehbouni, A., Kerr, Y., and Goodrich, D. (2006). A downscaling method for distributing surface soil moisture within a microwave pixel: Application to the Monsoon '90 data. *Remote Sensing of Environment* **101**, 379-389.

Rodriguez, J.-C., Watts, C., Chehbouni, A., Grageda, J., and Garatuza, J. (2006). Use of evaporative fraction to estimate daily evapotranspiration for several irrigated crops in northwest Mexico. *In* "2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II)" (J. Sobrino, ed.), pp. 573-578. Publicacions de la Universitat de València, Valencia, Spain.

Simonneaux, V., Duchemin, B., Chehbouni, G., Cherkaoui, M., and Kharrou, H. (2006). "SAMIR", a tool for evapotranspiration assessment using remote sensing. *In* "2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II)" (J. Sobrino, ed.), pp. 597-601. Publicacions de la Universitat de València, Valencia, Spain.

Simonneaux, V., Métral, J., Kharrou, H., Cherkaoui, M., Duchemin, B., and Chehbouni, G. (2006). SAMIR, "Satellite Monitoring of Irrigation" : a tool for irrigation monitoring using remote sensing for landcover mapping and evapotranspiration estimation. pp. 2nd International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS'II), Valencia, Spain.

Simonneaux V., Helson D., Duchemin B., Chehbouni G., Cherkaoui M., Kharrou H., 2006, SAMIR, un logiciel pour la spatialisation de l'évapotranspiration par télédétection. Application à l'aide à la gestion de l'irrigation dans la plaine du Haouz, Marrakech, Maroc. Colloque International GIRE3D, Faculté des Sciences Semlalia, 23-25 mai 2006, Marrakech, Maroc.

2005

Chehbouni, A., Escadafal, R., Boulet, G., Duchemin, B., Simmonaux, V., Dedieu, G., Hanich, H., and Er-Rouane, S. (2005). Integrated modelling and remote sensing approach for sustainable management of water resources in a semi-arid basin in Morocco (SUDMED AGU, Fall Meeting). New Orleans, USA ?

Chehbouni, A., Escadafal, R., Merlin, O., Boulet, G., Duchemin, B., Simonneaux, V., Dedieu, G., Mougenot, B., Olioso, A., and Hanich, H. (2005). Integrated modelling and remote sensing approach : toward a sustainable management of water resources in arid and semi-arid regions. *In* "Conference on Remote sensing and geoinformation processing in the assessment and monitoring of land degradation and desertification", pp.?, Trier, Germany.

Coret, L., Briottet, X., Kerr, Y., and Chehbouni, A. (2005). Experimental study of the directional aggregation of radiance and temperature over heterogeneous surface in the thermal infrared. *Remote Sensing of Environment*

Dedieu, G., Coret, L., Maisongrande, P., Boone, A., Gouaux, P., and Ducrot, D. (2005). Coupling satellite data and simple models to estimate crop water balance and irrigation requirements at regional scale. *In* "IAHS (International Union of Geodesy and Geophysics) Scientific Assembly", Foz do Iguaçu, Brazil.

Er-Raki, S., Chehbouni, A., Guemouria, N., Ezzahar, J., Hadria, R., and Chehbouni, A. (2005). Using of the FAO -56 model for estimating actual evapotranspiration of olives orchards in semi arid region. *In* "Congrès International sur les Méthodes d'Approximation et Modélisation Numérique en Environnement et Ressources Naturelles (MAMERN 2005)", pp. 1-2, Oujda, Maroc.

Escadafal, R. (2005). International Workshop on "Satellite Images Processing for Irrigation Monitoring", 29 Nov-4 Déc 2004, Amman (Jordan). Lectures, notes and exercices (H. de Bruin, B. Duchemin, O. Hartogensis). CESBIO Toulouse, France.

Escadafal, R. (2005). "IRRIMED : Improved management tools for water-limited irrigation: combining ground and satellite information through models - Annual Report Year II covering period from April 1st 2004 to March 31 2005." European Commission INCO-DC : International Cooperation with Developing Countries.

Escadafal, R. (2005). Remote sensing of land surface for monitoring arid mediterranean environments. *In* "Geomatics for land and water management - Achievements and challenges in the Euromed Context, International workshop" (R. Escadafal and M. Parachini, eds.), pp. 35-42, JRC, Ispra, Italy.

Escadafal, R., and Paracchini, M. (2005). "Geomatics for Land and Water management : achievements and challenges in the Euromed context. Proc.intern.workshop. JRC, 23-25 june 2004," European Communities EUR 21647 EN, Ispra, Italy.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Chehbouni, A., Er-Raki, S., Guemouria, N., and Hadria, R. (2005). The use of the eddy covariance technique for estimating and monitoring water consumption of olive orchards in a semi-arid region (Morocco). *In* "2ème Congr. Méditerranéen "Ressources En Eau Dans Le Bassin Méditerranéen : WATMED 2"", pp. CD-ROM, Marrakech, Maroc.

Ezzahar, J., Chehbouni, G., Hoedjes, J., Chehbouni, A., Er-Raki, S., De-Bruin, H., and Hadria, R. (2005). Combined a large Aperture Scintillometer and the aggregation model to integrate Area-averaged sensible and latent heat fluxes over two adjacent fields of olive. *In* "European Water Resources Association (EWRA) 6th International Conference", pp. 2, Menton, France.

Hagolle, O., Lobo, A., Maisongrande, P., Cabot, F., Duchemin, B., and De-Pereyra, A. (2005). Quality assessment and improvement of temporally composited products of remotely sensed imagery by combination of VEGETATION 1 and 2 images. *Remote Sensing of Environment* **94**, 172-186.

Martin, C. (2005). Apport des données de l'Infra Rouge Thermique directionnelles pour la partition des flux de surface. Stage, ENSICA, Toulouse, France.

Merlin, O., Chehbouni, A., Kerr, Y., Njoku, E., and Entekhabi, D. (2005). A Combined Modeling and Multispectral/Multiresolution Remote Sensing Approach for Disaggregation of Surface Soil Moisture : Application to SMOS Configuration *IEEE Transactions on Geosciences and Remote Sensing* **43**, 2036-2050.

2004

Abourida, A., Errouane, S., and Chehbouni, A. (2004). Use of remote sensing and GIS for the study of water resources in the Tensift region (Morocco). *In* "Geomatics for land and water management - Achievements and challenges in the Euromed Context, International workshop" (R. Escadafal and M. Paracchini, eds.), pp. 241-245, JRC, Ispra, Italy.

Benhadj, I., Duchemin, B., Maisongrande, P., Boulet, G., Chehbouni, A., Er-Raki, S., Escadafal, R., Ezzahar, J., Hadria, R., Helson, D., Hoedjes, J., Lahrouni, A., Khabba, S., Mougenot, B., Olioso, A., and Simonneaux, V. (2004). Etalonnage spatialisé d'un modèle agro-météorologique en milieu semi aride. *In* "Atelier de Modélisation de L'Atmosphère (AMA2004)", pp. 4, Toulouse, France.

Boulet, G., Chehbouni, A., Braud, I., Duchemin, B., and Lakhal, A. (2004). Application of a Two-Stage Evaporation Approximation a Semi-Arid Environment. *In* "1st General Assembly of European Geosciences Union (EGU)", Nice, France.

Boulet, G., Chehbouni, A., Braud, I., Duchemin, B., and Lakhal, A. (2004). Evaluation of a two-stage evaporation approximation for contrasting vegetation cover. *Water Resources Research* **40**, W12507.

Cheggour, A., Errouane, S., Simonneaux, V., Chehbouni, A., and Abourida, A. (2004). Interest of the geographic information system for the management of natural resources in the Tensift region. pp. 32nd IGC, Florence, Italy.

Coret, L., Briottet, X., Kerr, Y., and Chehbouni, A. (2004). Simulation Study of View Angle Effects on Thermal Infrared Measurements over Heterogeneous Surfaces. *IEEE Transactions on Geosciences and Remote Sensing* **42**, 664-672.

De-Bruin, H., and Hartogensis, O. (2004). Variance method to determine turbulent fluxes of momentum and sensible heat in the stable atmospheric surface layer. *Boundary Layer Meteorology* **116**, 385-392.

De-Bruin, H., Hartogensis, O., Allen, R., and Kramer, J. (2004). Regional Advection Perturbations in an Irrigated Desert (RAPID) experiment. *Theor. Appl. Climatol.* **80**, 143-152.

Dedieu, G., Chehbouni, A., Menaut, J., Boone, A., Ceschia, E., Coret, L., Gouaux, P., Hoedjes, J., Maisongrande, P., and De-Rosnay, P. (2004). Integrated approach of land surface functioning at the regional scale: the hows and whys from the "sud-ouest" project experience. *In* "1st General Assembly of European Geosciences Union (EGU)", pp.?, Nice, France.

Er-Raki, S., Chehbouni, G., Guemouria, N., Ezzahar, J., Williams, D., Boulet, G., Duchemin, B., Hadria, R., Lakhal, A., and Rodriguez, J.-C. (2004). Sap-flow-scaled transpiration responses to climate and soil moisture in an olive (olea europaea L.) orchard in Marrakech, Morocco. *In* "1st General Assembly of European Geosciences Union (EGU)", Vol. 6, pp. 00787. European Geosciences Union, Nice, France.

Escadafal, R. (2004). IRRIMED : Improved management tools for water-limited irrigation: combining ground and satellite information through models - Annual Report Year I covering period from April 1st 2003 to March 31 2004. pp. 114. European Commission INCO-DC : International Cooperation with Developing Countries.

Escadafal, R. (2004). "IRRIMED : Improved management tools for water-limited irrigation: combining ground and satellite information through models - Annual Report Year I covering period from April 1st 2003 to March 31 2004." European Commission INCO-DC : International Cooperation with Developing Countries.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Er-Raki, S., Chehbouni, A., Lakhal, A., Duchemin, B., Hadria, R., Boulet, G., and Bonnefond, J. (2004). Integrated sensible heat flux measurement over different-surfaces using a Large Aperture Scintillometer. pp. International Conference on Integrated Water Resources Research and Development in southeastern Morocco, IMPETUS Project, Ouarzazate, Morocco.

Ezzahar, J., Chehbouni, G., Hoedjes, J., Er-Raki, S., Duchemin, B., Boulet, G., Chehbouni, A., Gentine, P., Hadria, R., Lakhal, A., and Debruine, H. (2004). Integrated sensible heat flux measurement over two surfaces of olive using scintillometry. *In* "1st General Assembly of European Geosciences Union (EGU)", Vol. 6, pp. 01641. European Geosciences Union, Nice, France.

Ezzahar, J., Chehbouni, G., Hoedjes, J., Er-Raki, S., Lakhal, A., Rodríguez, J.-C., Chehbouni, A., Boulet, G., Duchemin, B., Gentine, P., Hadria, R., and Guemouria, N. (2004). Large aperture scintillometer used over a homogeneous irrigated area. *In* "Séminaire sur la Modernisation de l'Agriculture Irriguée dans les Pays du Maghreb - Projet INCO-WADEMED", pp. 6, Rabat, Morocco.

Hadria, R., Duchemin, B., Lahrouni, A., Khabba, S., Boulet, G., Chehbouni, A., Dedieu, G., Er-Raki, S., Ezzahar, J., and Lakhal, A. (2004). Calibration of the STICS crop model using remote sensing data to assess wheat evapotranspiration and water requirement in a semi-arid region (Marrakech, Morocco). *In* "1st General Assembly of European Geosciences Union (EGU)", Vol. 6, pp. 07415. European Geosciences Union, Nice, France

Hartogensis, O., and De-Bruin, H. (2004). Monin-Obukhov similarity functions of the structure parameters of temperature and turbulent kinetic energy dissipation rate in the stable boundary layer. *Boundary Layer Meteorology* **116**, 253–276.

Hoedjes, J., Chehbouni, A., Ezzahar, J., Gentine, P., Boulet, G., Duchemin, B., Escadafal, R., Simonneaux, V., De-Bruin, H., Dedieu, G., Su, Z., and Troch, P. (2004). An evaluation of two methods for the validation of models for the estimation of surface fluxes. *In* "1st General Assembly of European Geosciences Union (EGU)", Vol. 6, pp. 04703. European Geosciences Union, Nice, France.

Hoedjes, J., Chehbouni, A., Ezzahar, J., Hartogensis, O., De-Bruin, H., and Chehbouni, A. (2004). Application of Large Aperture Scintillometers over high, relatively sparse, irrigated vegetation in semi-arid conditions. *In* "Workshop on Scintillometry", pp. 23, De Bilt, The Netherlands.

Maisongrande, P., Duchemin, B., and Dedieu, G. (2004). VEGETATION/SPOT - An Operational Mission for the Earth Monitoring : Presentation of New Standard Products. *International Journal of Remote Sensing* **25**, 9-14.

Merlin, O., and Chehbouni, A. (2004). Different approaches in estimating heat flux using dual angle observations of radiative surface temperature. *International Journal of Remote Sensing* **25**, 275-289.

Merlin, O., Chehbouni, A., and Kerr, Y. (2004). A downscaling method for distributing surface soil moisture within a microwave pixel: application to monsoon'90 data. *In* "Microwave radiometry and remote sensing applications", Rome, Italy.

Pellenq, J., and Boulet, G. (2004). A methodology to test the pertinence of remote-sensing data assimilation into vegetation models for water and energy exchange at the land surface. *Agronomie* **24**, 197-204.

Rodriguez, J.-C., Duchemin, B., Hadria, R., Watts, C., Garatuza, J., Chehbouni, A., Khabba, S., Boulet, G., Palacios, E., and Lahrouni, A. (2004). Wheat yield estimation using remote sensing and the STICS model in the semiarid Yaqui valley, Mexico. *Agronomie* **24**, 295-304.

Samaan, S. (2004). Evapotranspiration of the Palmyra oasis. Comparison between actual evapotranspiration and estimation of crop evapotranspiration using the FAO Kc approach. Stage, Homs, Syria.

2003

Abourida, A., Errouane, S., Simonneaux, V., Chehbouni, G., and Cheggour, A. (2003). Determination of the Water Volumes used for Irrigation in the Haouz Plain by Remote Sensing. *In* "23th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'03)", Vol. 4, pp. 2948-2949, Toulouse, France.

Chehbouni, A., Escadafal, R., Dedieu, G., Er-Rouane, S., Boulet, G., Duchemin, B., Mougenot, B., Simonneaux, V., Seghieri, J., and Timouk, F. (2003). A multidisciplinary program for assessing the sustainability of water resources in semi-arid basin in Morocco: SUDMED. *In* "EGS AGU EUG Joint Assembly", Vol. 5, pp. 14229. European Geophysical Society, Nice, France.

Chehbouni, A., Kerr, Y., Lagouarde, J.-P., Watt, C., De-Bruin, H., Rodriguez, J.-C., and Boulet, G. (2003). Potential and limitations of using the large aperture scintillometer to estimate area averaged surface fluxes over heterogeneous surfaces (EAE03-A-14205). *In* "EGS AGU EUG Joint Assembly", Vol. 5, pp. 14205. European Geophysical Society, Nice, France.

Duchemin, B., Er-Raki, S., Gentine, P., Maisongrande, P., Coret, L., Boulet, G., Rodriguez, J.-C., Simonneaux, V., Chehbouni, A., Dedieu, G., and Guemouria, N. (2003). Estimating cereal evapotranspiration using a simple model driven by satellite data. *In* "23th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'03)", Vol. IV, pp. 2762-2764, Toulouse, France.

Duchemin, B., Hadria, R., Rodriguez, J.-C., Lahrouni, A., Khabba, S., Boulet, G., Mougenot, B., Maisongrande, P., and Watts, C. (2003). Spatialisation of a Crop Model using Phenology derived from Remote Sensing Data. *In* "23th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'03)", Vol. , pp. 3, Toulouse, France.

Lakhal, A., Boulet, G., Lakhal, E., Er-Raki, S., Duchemin, B., Chehbouni, G., and Timouk, F. (2003). Designing a simple physically-based bucket SVAT model for spatialisation of water needs. *In* "EGS AGU EUG Joint Assembly", pp. 1. European Geophysical Society, Nice, France.

Maisongrande, P., Coret, L., Duchemin, B., Gouaux, P., Dedieu, G., Chehbouni, A., Habets, F., Calvet, J., and Noilhan, J. (2003). Interannual monitoring of evapotranspiration in Midi-Pyrenees with SPOT/VEGETATION. pp. 23th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'03) A38 (Water Resources), Toulouse, France.

Pellenq, J., Kalma, J., Boulet, G., Saulnier, G., Wooldridge, S., Kerr, Y., and Chehbouni, A. (2003). A disaggregation scheme for soil moisture based on topography and soil depth. *Journal of Hydrology* **276**, 112-127.

Pellenq, J., Kerr, Y., and Boulet, G. (2003). Scaling and Assimilation of SMOS Data for Hydrology. pp. 23th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'03), Toulouse, France.

Simonneaux, V., and François, P. (2003). Identifying main crops classes in a irrigated area using high resolution image time series. *In* "23th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'03)", Vol. 1, pp. 252-254, Toulouse, France.

Abourida, A., Errouane, S., Chehbouni, A., and De-Solan, B. (2002). Use of satellite images to estimate the discharge by pumping of the Haouz Aquifer of Marrakech. pp. 1st International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS), Valencia, Spain.

Boulet, G., Chehbouni, G., and Kerr, Y. (2002). Assimilation of dual angle temperatures in a SVAT model : application of an Ensemble and an Extended Kalman Filter. *In* "22th International IEEE Geoscience and Remote Sensing Symposium (IGARSS'02)", pp. 3, Toronto, Canada.

Duchemin, B., Maisongrande, P., Frappart, F., Magnac, M., Chehbouni, G., Dedieu, G., and Mougenot, B. (2002). Monitoring of Wheat Crop Evapotranspiration and Irrigation in Arid Conditions using Phenology derived from Optical Satellite Data. *In* "1st International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS)" (J. Sobrino, ed.), pp. 177-183. Publicacions de la Universitat de València, Valencia, Spain.

C.7 conclusion

In conclusion, according this publication list, the project can be considered a scientific success. More broadly, after 4 intense years of work, its benefits can be summarised this way :

- new knowledge on the evapotranspiration assessment in the field, development of models predicting ET and crop development, simplified versions used in combination with satellite to obtain biomass and ET maps (numerous peer reviewed publications)
- intense transfer of know-how and technology through 3 international workshops gathering the young scientists in Syria, Jordan and Tunisia (with hands-on exercises and internet support)
- strong involvement of the end-users as full stakeholders in the project deployment, adjustment of the objectives and methods to their actual needs
- reinforcement of north south, but also south-south cooperation in the building a scientific community spirit around the theme of monitoring agricultural water in the Mediterranean region.

Follow up: participants to the project have all concluded that it has been a success and they were all wishing a follow up. As a matter of fact the success can be also gauged by the fact that it attracted attention of other research groups. Partners 1,6 and 7 have been invited to join the large PLEIADeS consortium, an FP6 Global Change project, focusing on Earth Observation for better irrigation management at the local level. Our group will be involved mainly in EO methods and testing the project applications on the Moroccan regional site.

(www.pleaides.es)

D Management report

D.1 Organisation of the collaboration

The project website has been part one important tool for collaboration withn the project, offering the following features:

- advanced on line project library (downloadable documents produced by the project, and reference documents for students) in English and in French [see annex]
- news pages describing current experiments
- members pages for internal news and exchanges
- didactic documents showing the scientific principles of the project (with illustrations and animation in Macromedia Flash format)
- links towards the institutions involved and research projects of interest.

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D.2 meetings

Along the project life, four important meetings have been organised and hosted by different partners. In brief:

- The **kick-off meeting**, organised by the coordinator (partner 1), took place in CESBIO Toulouse, 22-23 May 2003. The implementation plan of the different activities has been refined and some adjustments have been decided. A visit of the 'Cité de l'Espace' has concluded this event.
- The **second project meeting**, has been hosted by partner 9 (INRGREF) in Tunis 21-23 April 2004, Hotel Belvédère, to review the progress and results and to plan the second year activities. A field trip to the Tunisian test site of Kamesh has followed
- The **third project meeting**, has been hosted by the Faculty of Sciences Semlalia (partner 6) in Marrakech, Morocco, 14-16 April 2005, to review the progress and results and to plan the next steps of project activities, it has been followed by a filed trip to visit the irrigation saving experiments.
- The **final project meeting**, has been organised by the Ministry of Water and Irrigation (partner 6) at the Dead Sea in Jordan 2-4 March 2007. After the official opening by His Excellency Secretary General of Water and Irrigation, all partners worked during two days under the guidance of the coordination team, to sum up the results and conclusions of the project. A field visit has been organised and the third day was devoted to the final discussion with the end-users (see Annex II).

D.3 exchanges and training

D.3.1 Exchanges

Whereas exchanges have been frequent through email and phone, in addition to the meetings cited above major exchanges occurred during the visits:

- visit of Prof. H.de Bruin and O.Hartogensis (partner 2) to the Jordanian partners (dec.2003) : visit of Ms. Suzan Taha, director at MWI (partner 5) to the moroccan partners (evaluation of the endusers requirements)
- 2004: visit of J. Hodges , PhD student in micrometeorology at CESBIO, to the tunisian partners
- 2004: visit of Dr Feras Ziadat to Marrakech meeting with IRD and Moroccan partners
- 2005: visit of the coordinator to the Jordanian partners and to the experimental test sites in the Jordan valley (discussions on strategy for 'ground truthing' and satellite imagery acquisition, on Ph.D. work of M.Jitan, and work plans for the coming agricultural seasons)
- 2006:prof. Feras ZIADAT from the University of Jordan (partner 3), was invited by the coordinator to CESBIO in Toulouse France, to discuss the results of the special campaign on the Jordan Valley. During this experiment, a series of 12 Spot satellite images was acquired, whereas field sampling and radiometric measurements where performed. Prof. Ziadat visit allowed to analyse the measurements and to combine field and satellite records.

D.3.2 training

- the **first training workshop in Palmyra** , Syria. Organised by ACSAD in the historical oasis of Palmyra. During 5 full days, 33 participants from 6 countries involved in IRRIMED have followed the lectures and practiced hands-on exercises on micrometerological methods **for measuring evapotranspiration over crops. exch**anges and training
- The **second training workshop** hosted in Amman by partner 3, the College of Agriculture of the University of Jordan, has been dedicated to the **remote sensing** aspects (led by CESBIO-IRD, partner1). During 4 days, the participants from all southern partner countries have followed the lectures and practiced hands-on exercises on satellite image processing for mapping evapotranspiration over crops.
- Scientists and trainers have also interacted with the end-users during a **special workshop** organised by the Ministry of Water and Irrigation as part of workpackage 6 (see partner 5 report).
- The **third IRRIMED Workshop** on **« crop water modelling tools »**. Hosted in Hammamet Tunisia by partner 9 (INRGREF) , IRRIMED workshop Tunis, November, 28th to December 2nd 2005 has been led by CESBIO-IRD (partner1),

D.4 Financial problems

The delays in starting the project and then in obtaining the first reimbursements (depicted in details in the annual reports) had forced some partners to relax their experimental plans. This had led the consortium to request a 12months extension of the duration of the project. The second reimbursements occurred in August 2006, that is in the forth year of the project, so the new duration of the contract (expanded to 48 month) was really necessary to allow the full deployment of the activities planned. During the final meeting we could all conclude that this extension has also been sufficient as all delays had been compensated during the fourth year.

E Individual partners reports

Note about the figures inserted: they are numbered within the relevant section, to make the numbering simpler.

E.1 Report of partner 1 (IRD/CESBIO, France)

While in charge of the coordination (by Dr. Richard Escadafal) IRD-cesbio, has been also involved in various specific scientific tasks in close cooperation with the different partners.

E.1.1 WP 8 : project management and scientific steering

IRD has been in charge of the project management and scientific coordination, the activities relevant to this workpackage have been described in the first part (section D).

E.1.2 Activities and results per workpackages

The activities reflected in this section have been carried out by the following research scientists:

- Dr. A.Ghani Chehbouni, science team leader
- Dr. Gilles Boulet, Dr. Benoît Duchemin, Dr. Vincent Simonneaux

with important contributions from the Ph.D students :

- Iskander Ben Hadj, Anne Chaponnière, Joost Hoodges

and numerous master students (see references). These contributions have been described in details in the annual reports. IRD has been intensively involved in WP 1 to 4 as reflected in the publications list. A large part of them is authored or co-authored by IRD scientists. Here we review briefly some of the important contributions.

E.1.2.1 WP1

In collaboration with partner 3 and 6, an important part of the WP1 has been to develop a technique to map the land cover of the test area. The best results have been obtained by using the changes in vegetation indices as a criteria for distinguishing main land cover types: permanent vegetation (such as trees) from annual crops (fig.1) (Simonneaux et al., 2003, 2007)

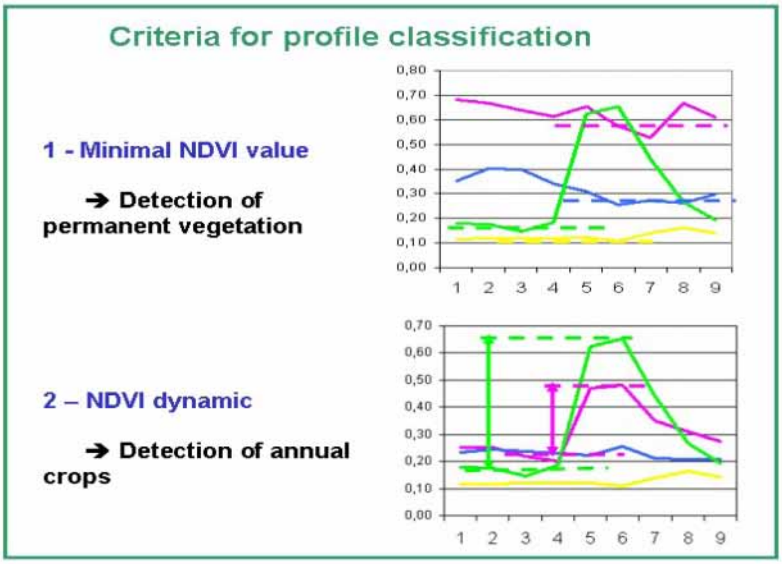


Figure 1. Temporal profile (by months) of satellite derived vegetation indices (NDVI) as criteria for land cover classification

Figure 2 illustrates the result in the case of the map covering the Haouz plain (Moroccan test site). Although the typology obtainable is not very detailed, it is sufficient in first approximation for water budget assessment over the whole plain (using the FAO method, see WP4).

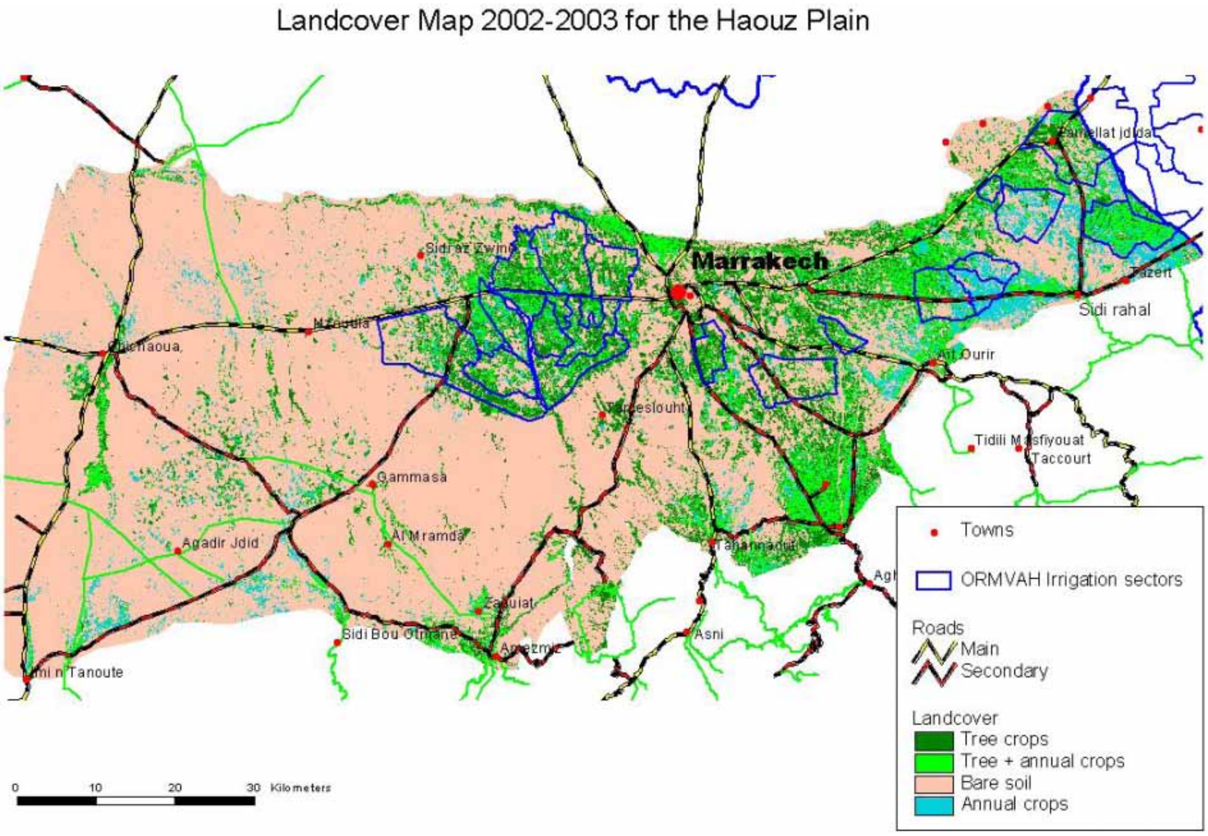


Figure 2. Land cover map obtained by the temporal NDVI profile method over the Haous plain (Moroccan test site)

In order to refine the results obtained IRD-CESBIO has further developed the temporal profile an a joint experiment with the Jordanian team, on the use of a series of 12 Spot images over the Jordan valley during the 2005-2006 growing season. The results of this intense crop monitoring activity made possible with the support of the CNES-ISIS program, are illustrated in the individual report of Partner 3.

E.1.2.2 Contribution to WP3

E.1.2.2.1 WP3 Context:

The WP3 faces two challenges:

- For a given irrigation, how much water is actually available to the plant ? What is for instance the importance of the soil evaporation and the drainage components for the three dominant vegetation types ?
- What tool is better suited to model and predict these different components for a given range of spatial and temporal scales ?

Both questions can be answered by using Soil-Vegetation-Atmosphere Transfer (SVAT) models of contrasting degrees of complexity. The simplest ones (also named “operational”) give rough estimates of the main water-cycle components; say at the minimum a daily total evapotranspiration (ETR).

The most complex ones (also named "reference") compute the detailed mechanisms of any physical process of water and energy exchange between the soil, the plant and the atmosphere, including some processes that could be neglected under most circumstances, like the vapour transfer within the soil. They are often applied at the plot scale and for short periods of time, with a very small time-scale, typically a few minutes to one hour. Within WP3, one want

1- to assess the relative pertinence of use and performance of each model at the plot scale, and

2- to improve deficient "simple" model formulations on the basis of "reference" model formulations.

Thus this model selection or model development involves two different uses of the experimental data acquired during WP2 :

i) a comparative study of the relative performance of each model for total ETR estimation (use of the WP2 ETR)

ii) ia selection of the pertinent component analytical formulations within the "reference" models, such as soil evaporation, to improve the corresponding component in the "operational" models (use of all the water and energy fluxes measured in WP2).

One must note that even if the physics in the "reference" models provides an up-to-date and exhaustive representation of the different water and energy exchange processes at the earth's surface, the value of many physical input parameters is not known with a good accuracy. Therefore these parameters have to be adjusted in a calibration procedure on the basis of the available local measurements. The assumption in IRRIMED is that, once the unknown parameters are derived through calibration on local data for a given vegetation type, "reference" models can be applied for the same vegetation type to other climates, soils, and irrigation practices, either real (elsewhere) or virtual (scenarios).

E.1.2.2.2 Typology of the different SVATs implemented within WP3:

Four "SVAT" models are developed and/or implemented within WP3. They can be compared in terms of complexity, level of physics, and typical spatial scale of application (see Figure 3 and Table 1).

The *FAO56* model (Allen et al., 1998) is widely used for operational purposes, including irrigation scheduling. Its formulation is generic and semi-empirical and therefore its applicability for contrasting soil, vegetation, climate and irrigation conditions is questionable. For instance, the length of the growing season given in the manual for most cereals is valid for temperate regions of the globe but not the semi-arid climate, which shows a quicker transition from one phase to the other. The different growth stages for the dual-crop coefficients within the *FAO56* are constrained according to observed phenology patterns deduced from NDVI time series. This model is used at the daily time-scale.

The initial *SVATsimple* model (Boulet et al., 2000) has been developed for sparse semi-arid short natural vegetation (such as grass). It assumes that the rooting system is limited to the shallow subsurface soil, and that the vegetation is always close to stress conditions (low rainfall). Therefore, it is not suited to gravity irrigation. It has been extended to the later case within the frame of IRRIMED and tested for synthetic data-sets against *SiSPAT* (Boulet et al., 2004). It is an analytical analog of *SiSPAT* under specific assumptions, and can be seen as the physically-based version of the FAO56 method, with which it shares several common features (bucket water budget, single source energy balance, daily time step…).

Although the model is based on a daily time-scale, an hourly energy balance can be computed to derive the diurnal fluctuations of the different energy fluxes and the surface radiative temperature. These two simple models describe the soil evaporation and the transpiration separately, for two patches side-by-side. *SiSPAT* takes into account the coupled water and energy transfer in the soil and describes the water vapour transfer. It is thus used to investigate the simplification of the water transfer in the soil system. Similarly, *ICARE-SVAT* (Gentine et al., 2007) is a modular complex model that is used to investigate different combinations of stomatal resistance formulations (namely Monteith and Jarvis) and soil water transfer discretisation (namely the Force-Restore and the Diffusion-Gravity equations). It is coupled to a simple vegetation functioning model. Both SiSPAT and ICARE-SVAT have a two-source interface that allows for the description of the interacting sources of heat represented by a "big pore" (single heat source for the soil) and a "big leaf" (single source for the vegetation).

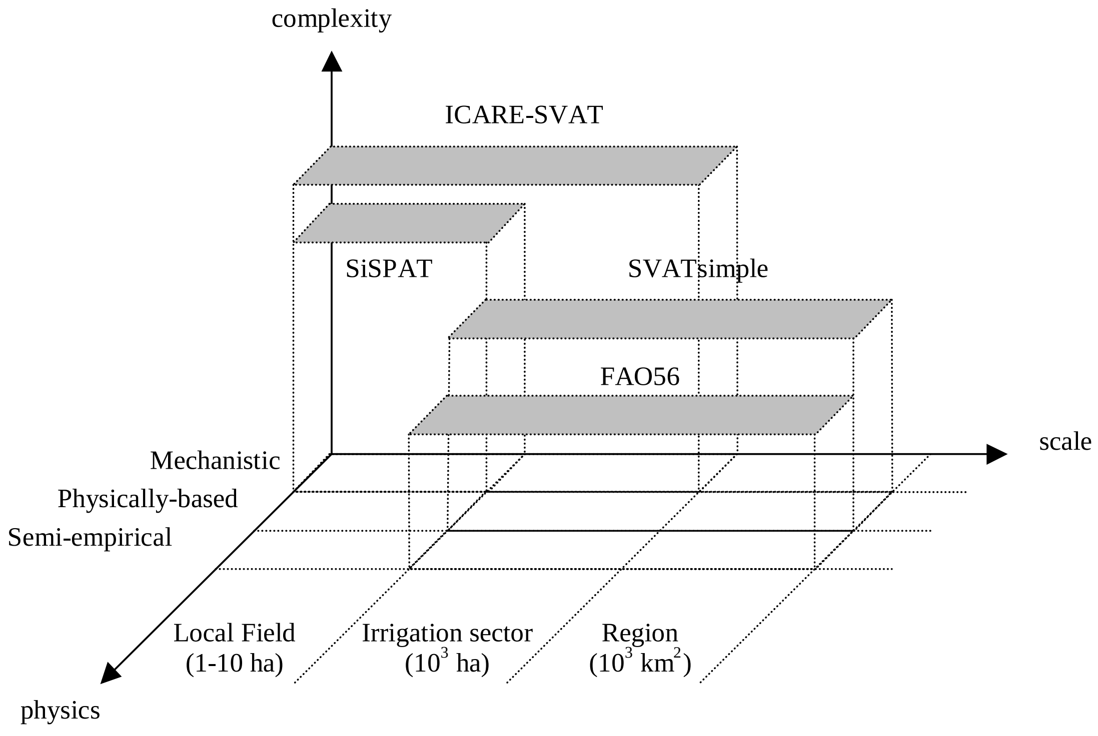


Figure3 : scale/complexity diagram of the different SVATs models implemented within IRRIMED

MODEL NAME	MODEL TYPE	MODEL USE	REMOTE SENSING	SITE APPLICATION
SiSPAT Braud et al. (1995)	Dual source (Soil+Vegetation) Soil-Plant-Atmosphere interface Coupled heat and water transfer in the soil, under both vapour and liquid states	**Reference** model, used for - Selecting pertinent soil water processes at the local/plot scale - Development and improvement of simpler schemes (see 4.1)	None	- 2 Olive trees site - 3 wheat sites (2003)
ICARE-SVAT Gentine et al. (2007)	Dual source Soil-Plant-Atmosphere interface Simplified Diffusion-gravity equation or Force-Restore scheme Coupled with a simple vegetation functioning model	**Reference** model, used for - Selecting pertinent soil or stomatal resistance modules at the plot scale - Remote-Sensing Data Assimilation - Investigating the coupling with a vegetation functioning model - Spatialisation	Designed to assimilate NDVI and Directional surface temperature (see 4.3)	- idem SiSPAT + - Saada2 orange tree site
SVATsimple Boulet et al. (2000) and Boulet et al. (2004)	One source (either soil or vegetation) Soil-Plant-Atmosphere interface Simple bucket	**Analytical analog** of SiSPAT under specific assumptions, used for - Remote-Sensing Data assimilation and - Improvement of hydric stress scheduling in FAO56 - Spatialisation	Designed to use nadir surface temperature in a calibration mode, and NDVI as vegetation forcing (see 4.2)	- idem SiSPAT + - R3 irrigation sector
FAO56 Allen et al. (1998)	One source (either soil or vegetation) Simple bucket	**Operational** model, used for - Spatialisation - Operational applications - Future DSS	Designed to use NDVI to describe phenology and improve cultural coefficients	- idem SiSPAT + - R3 irrigation sector + - Whole Haouz plain

Table 1: SVAT models implemented within IRRIMED

E.1.2.3 Contribution to WP4

E.1.2.3.1 Development of the SAFY crop growth model

The SAFY ('Simple Algorithm For Yield estimates') model has been built based on the work of Monteith (1965) which has developed a simple approach to link the production of dry phytomass with photosynthetically active radiation absorbed by plants. The SAFY model includes three subsets of equations to simulate the time courses of the dry above-ground mass (DAM), and the green leaf area index and grain yield. The DAM variable refers to as all the above-ground phytomass except grains. The climatic forcing variables include incoming global radiation and mean air temperature on a daily basis.

The dry above-ground mass increases during the period of photosynthetic activity, from plant emergence to complete leaf senescence. During this period, the production is driven by solar radiation through three factors :

1) the climatic efficiency, i.e. the ratio of incoming photosynthetically active to global radiation, which is well-known and relatively constant;

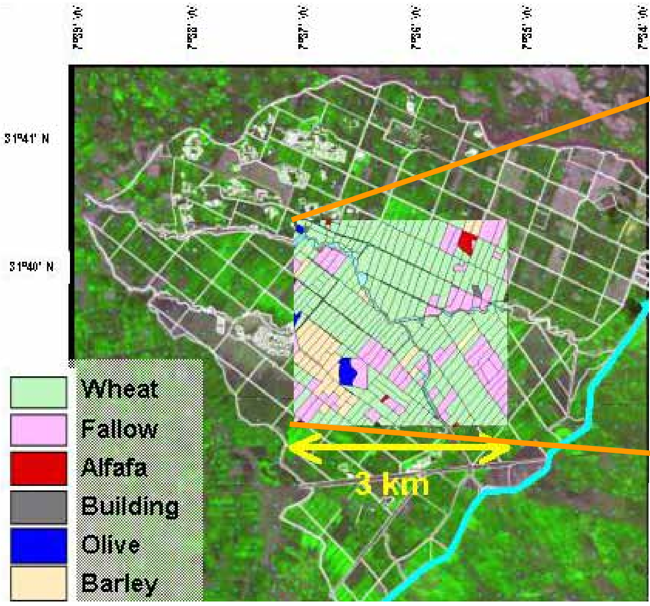
2) the light-interception efficiency, i.e. the fraction of photosynthetically active radiation that is absorbed by the canopy, which is calculated from the leaf area index based on the Beer's Law analogy;

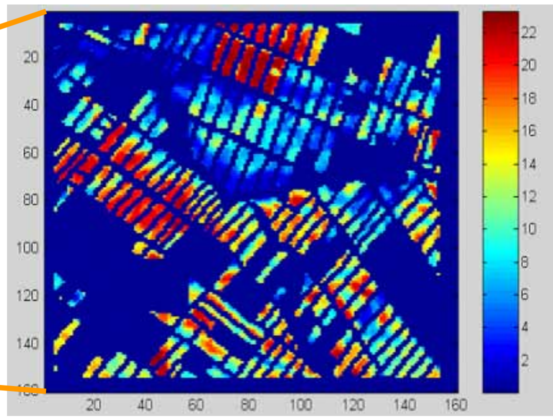
3) the light-use efficiency (LUE), i.e. the ratio of photochemical energy produced as dry above-ground mass. LUE accounts for the potential production, which depends on crop type, reduced by all the environmental stresses except temperature. Both high and low temperatures decrease the rate of dry phytomass production according to Brisson et al. (2003) and Porter and Gawith (1999).

The level of complexity of SAFY (6 equations, 14 parameters) is low in order to facilitate both the optimisation of parameters from RS and the control of results in space and time. A first class of 8 parameters groups *a priori* known parameters and includes the climatic efficiency, the light-interception coefficient, optimal and extreme values of air temperature for the plant photosynthetic activity, the specific leaf area and the initial dry-above mass. These parameters have been identified based on reasonable assumption, scientific literature or analysis of experimental data.

The second class includes the fourth phenological parameters which control leaf appearance during growth as well as the beginning and the rate of senescence. These parameters can not directly be obtained from observations and they require to be calibrated for a particular crop type and variety. The two last parameters, which witness for the agri-environmental conditions, are : the day of emergence, depending on sowing dates; and the light-use efficiency LUE, which is supposed to account for all the stresses (except temperature), e.g. soil hardness, artificial ploughing, absence or reduced fertilisation, drought. These two parameters have to be adjusted locally (field by field or pixel by pixel) because the agricultural practices know high variation within the test site.

Deriving vegetation parameters from the satellite image (see WP1) has been continued in WP4 to obtain GLAI input values for the SAFI model. The processing of the collection of satellite images resulted in a time series of GLAI images superimposable together, which was used to control the SAFY model by the inversion of the day of emergence and the light-use efficiency (same optimisation procedure than for the model validation). This procedure was repeated for each pixel cropped with wheat. It allows to map the wheat production on the test site for the 2002/2003 agricultural season (fig.3). It also results in time series of daily GLAI which can be used to control the FAO method or any other SVAT model in order to provide with daily estimates of the different terms of the water balance of wheat crop at a seasonal and regional scales.





(left) : Test site and 2002/2003 land cover

(top) : maps of dry aerial phytomass (t/ha) derived from the SAFY model and a time series of satellite images during the 2002/2003 season

Fig 3 applying the SAFY model to time series of satellite images to compute wheat phytomass (R3 test site, Morocco)

E.1.2.3.2 Monitoring irrigation with remote sensing : SAMIR prototype

Based a this type of models simple enough to be applied on a per pixel basis a development of the software prototype has been developped dedicated to assist irrigation management (SAtellite Monitoring of IRrigation, SAMIR, see Simonneaux et al. 2006). This is a good illustration of the effort to make converge scientific advances and endusers requirements: IRD and FSS worked closely with ORMVAH on this issue

From an operational point of view it has to be remembered that to assess the water budget at large scales, i.e. at the Haouz plain level, less data will be available than those obtained through the micromet experiments for the reference model validation/

As a result , there is a need to develop, test and validate simplified models have to be validated. The FAO model is the basis approach retained for ET estimation, which is the basis of any water budget.

ET estimation based upon the FAO method rely on the multiplication of a climatic component (ET0) and a crop coefficient (Kc) in order to obtain evapotranspiration for any kind of cover.

Based upon this approach initially designed for point estimates of ET (on a per field/crop basis) the SAMIR application is divided in two mains module :

ET = ET0 * Kc

Climate module, which allows the user to calculate the ET0.

Vegetation module, which calculates the Kc.

The ***Climate module*** allows several types of inputs, with various spatialisation levels. The last two options allow to take into account the spatial variability of the climatic condition. Currently these are best represented by the meteorological models, in our case the one run by the national met service (Direction de la Météorologie Nationale, Morocco). This gridded model allows even to input forecast data and thus to **predict** water demand rather than only monitoring it.

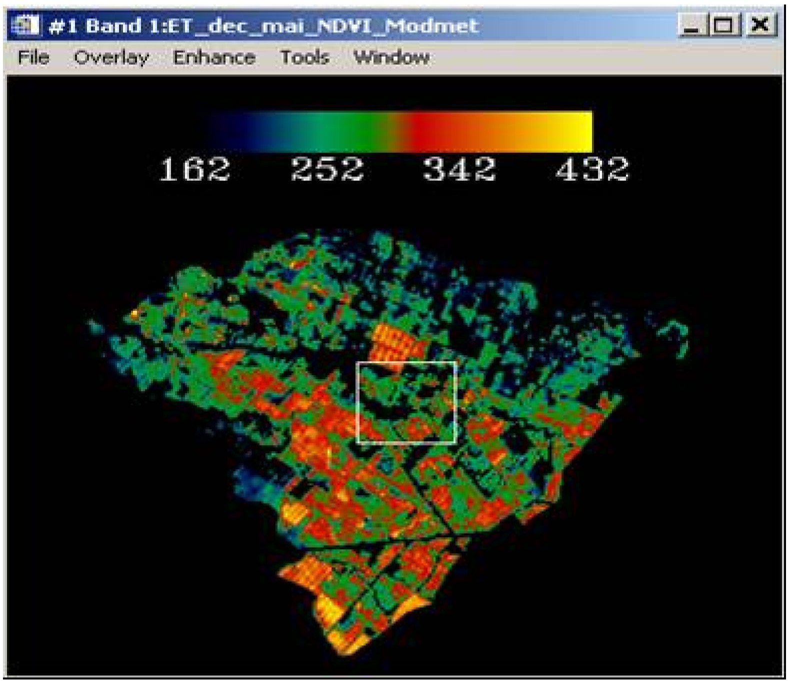
The **Crop development module** is based on the crop coefficient (Kc) curve describing the different development stages. These can be derived from statistics (out of the FAO book of from local observations). Spatialising the crop development requires to know the distribution of the main crops either statistically (case one of the table below) or as a map of average cropping pattern (case 2). In the method developed here we identify the crops and their development stage directly by monitoring their 'greeness' using the remotely sensed vegetation index (NDVI). This way we obtain the highest quality in crop coefficients spatialisation (Kc adjusted).

Crop development module

Land Cover Input	Crop calendar	KC VALUE	Spatialisation quality
Surface **statistics**	Statistics / climat	FAO Kc	None
land use over previous years (from satellite)	Statistics / climat	FAO Kc	Low, only landuse
Land cover of the year (NDVI)	Satellite Time Series	NDVI => Kc adjusted	High

By applying the simple FAO method equation, we combine the climate module to obtain ET0 and the KC adjusted to derive the evapotranspiration over a given period on a **per pixel** basis.

A first type of results is the production of evapo-transpriation maps (ET maps) such as the one obtained over the R3 test area representing the cumulated ET (in mm) for the period of December to May (figure below). The ET values are computed for each pixels ; however plots of similar crops appear clearly as groups of pixels forming rectangular shapes. At the same time big differences in ET are observed, even with the same group of fields. This example clearly illustrates the benefit of satellite imagery to monitor closely the water consumption by crops, compared to the usual estimates. It should be mentioned that this processing of satellite times series is providing with estimates for past periods, whereas managers and farmers are also very and maybe more interested in forecast. This is a much trickier problem as such forecast capabilities are closely linked to meteorological forecast in one hand, and also to a major extent to an accurate crop modelling, which is also rather difficult.



E.1.3 Other activities

IRD-cesbio, has also participated actively in establishing the relationships between the project scientific teams and the endusers. During this activity, lead by partner 5 (MWI) in charge of the WP6, IRD scientists have been heavily involved in presenting and discussing the methods and results and in interacting with the users to better understand their needs (see Partner 6 report and Annexes)

A strong emphasis has also been put on training of young scientists through both the workshops and the dissemination of their content through the internet. These trainings have fostered south south collaborations spirit among them (see).

E.1.4 Publications

See the full project publication list C6, with authors, Boulet, Chehbouni, Duchemin, Escadafal, Simonneaux

E.2 Report of partner 2 (WU, the Netherlands)

Scientists involved: Dr. Henk A. R. De Bruin (PI) and Dr. Oscar K. Hartogensis

E.2.1 Introduction

This overview summarises the annual reports that have been produced over the last four years. All activities of WU in the project relate to work package 2 (WP2) named "Micrometeorology". The main contribution of WU to the IRRIMED project was transfer of micrometeorological know-how to the group members in the project. This objective was reached in a number of ways:

- The micrometeorology workshop in Palmyra, Syria in February 2004.
- Joint micrometeorological field campaigns.
- Training of the groups of UoJ, Morocco and Tunisia in the use of scintillometers and/or eddy correlation systems in the field and using the eddy-correlation software developed at WU.
- Providing assistance in the interpretation of the results

E.2.2 Micrometeorological Training

E.2.2.1 Training course on Eddy-Correlation in Jordan.

From 11-19 December 2003 Oscar Hartogensis trained a Jordan team (5 participants) from UoJ and NCARTT in the Jordan Valley on how to use eddy-correlation (EC) equipment. The training consisted of the theoretical background of the method, the principle of operation of the sensors used, how to install the equipment, trouble shooting and quality control, data-collection of raw data with CR23X-Libretto laptop system, pre-processing, post processing raw data using EC software developed by WU. Mr. Hartogensis provided written materials to support this training course.

E.2.2.2 Micrometeorology Workshop at Palmyra, Syria

The IRRIMED *Workshop on Estimation of Actual Evapotranspiration and Crop-Water Requirements* was organized by ASCAD, IRD and WU and was hosted by ASCAD. It was held at Palmyra, Syria, from 8 - 12 February 2004. Drs Henk De Bruin (WU), Benoît Duchemin (IRD) and Oscar Hartogensis (WU) were the lecturers. Dr. De Bruin and Mr. Hartogensis of WU gave lecturers on theoretical background and methods of observation of actual evapotranspiration. Dr. De Bruin (WU) had written lecture notes and computer aided learning (CAL) interactive modules specially written for the workshop. The CAL modules were used under the supervision of Mr. Hartogensis, mostly during afternoon sessions.

E.2.2.3 General micrometeorological support

The groups of UoJ, Morocco and Tunisia received training in the use of scintillometers and/or eddy correlation systems through joint micrometeorological field experiments. In addition they learned how to store and manage raw eddy-correlation (EC) data and process these to fluxes by using the EC-pack eddy-correlation software developed at WU (http://www.met.wau.nl/projects/jep/index.html).
For the EC measurements taken at the Kamech river basin in Tunisia this data-treatment proved to be crucial in the interpretation of the results because the topography of the terrain required special co-ordinate transformations of the EC data which can not be performed on the datalogger itself.

The PhD students involved in this training are now experts in their region on micrometeorological observation methods.

E.2.3 . Research Results

E.2.3.1 Agdal experiment, Marrakech, Morocco

In the context of IRRIMED WU and CESBIO carried out a field experiment in the Agdal gardens near Marrakech to test the applicability of a large aperture scintillometer over olive trees. In addition, the same data set has been used to test remote sensing techniques for the determination of actual crop evapotranspiration. The experiment has been performed before the formal start of IRRIMED (September 2002 – February 2003), so the data collection itself is outside the scope of IRRIMED. As agreed, WU spent part of the IRRIMED funds to analyze the Agdal data set.

E.2.3.1.1 Applicability of methods to derive actual evapotranspiration from NOAA and LANDSAT images.

This research was carried out in the form of part of a MSc-thesis (Van Den Kroonenberg, 2003), which is made available to the IRRIMED community. The general conclusions are:
1. NOAA images are not suitable because the effective NOOA pixel size is too large compared to the field size at AGDAL.
2. One LANDSAT image gave a much better result, however, LANDSAT has the drawback that the number of suitable images per growing season is very limited.

E.2.3.1.2 The applicability of a large aperture scintillometers (LAS) to determine actual evapotranspiration of tall and sparse vegetation.

This research was carried out in the form of part of a MSc-thesis (Van Den Bersselaar, 2003), which is made available to the IRRIMED community. This study shows that the actual evapotranspiration evaluated from LAS data using 'standard' numerical procedures differ from the eddy correlation observations. The results just after ('wet') and just before irrigation ('dry') appear to be different. Moreover, advection appears to be important in case with high wind speed. Mr. Hartogensis (WU) found evidence that the so-called zero-plane displacement for tall and sparse vegetation depends on solar angle, by which it has a diurnal cycle. This issue is described in more detail in the next section.

E.2.3.1.3 Thermal displacement height for tall vegetation

The scintillometer measures the line average of the so-called structure parameter of temperature C_T^2. According to the Monin-Obukhov similarity theory (MOST) this is related to the sensible heat flux H. At low wind speeds and high solar radiation rate there is a simple relationship between C_T^2 and H¸ notably:

$$H = C_{Ct} \rho c_p (z-d)\left(C_T^2\right)^{\frac{4}{3}}, \quad (1)$$

where C_{Ct} is a constant, ρ is the density of air, c_p is the specific heat of air at constant pressure, z the height of the scintillometer beam and d the zero-plane displacement for sensible heat. In literature rule-of-thumb estimates for d are given. One of these is 0.7 times the vegetation height h_v.
For the Agdal data set this value appear to be wrong. So there is a need to study d for the olive trees present in the Agdal gardens. The zero-plane displacement has been introduced 'heuristically' to account for the fact that in case of tall vegetation turbulent 'eddies' effectively to not reach the ground, but a level d >0. However, the physical meaning of d yet not clear.

Intuitively, d is related to the 'effective' height of the source for sensible heat also. In this picture it is to be expected that for tall sparse vegetation d is related to the solar angle α. When α is small the top of the trees will be heated and d is expected to be large. On the other hand, the soil strips between the trees will be illuminated directly by the sun at high solar angles. We found that d can be evaluated from the collected the eddy correlation and the scintillometer observations. In Figure 1 the d evaluated in this way is plotted versus the sin(α) = cos(Z), where Z is the zenith angle ($Z = \pi/2 - \alpha$).

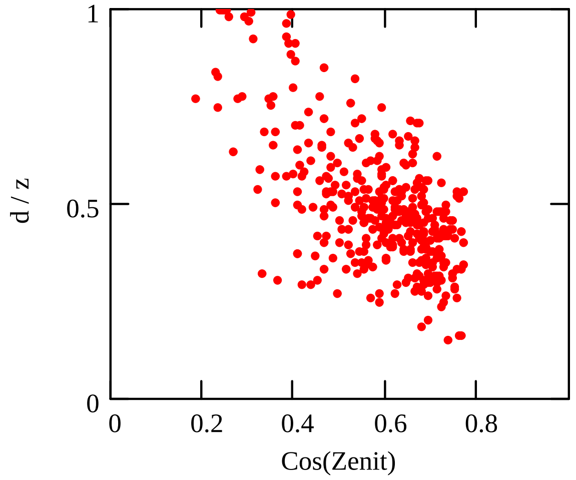


Figure 1: For daytime conditions the displacement height for C_T^2, d, normalized with the measurement height z versus the cosine of the solar zenit angle.

With d thus derived we improve the scintillometer H (in comparison with eddy correlation), with respect to taking a constant d in the flux calculations (See Figure 2).
Having shown that the concept of a variable d is plausible, next, we have presented a first step to model d, which we can then use in the scintillometer flux calculations independently of eddy covariance measurements.

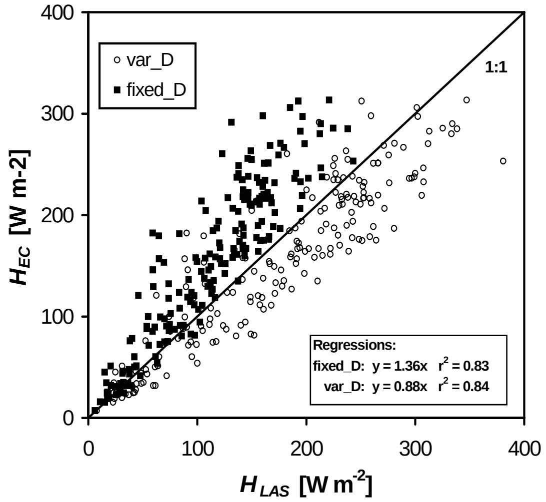


Figure 2: The eddy correlation heat flux, H_{EC}, versus the scintillometer heat flux, H_{LAS}. H_{LAS} was calculated with a fixed displacement height (fixed_D) estimated by 0.6*tree_height, and with a variable displacement height (var_D), where the displacement height was solved from eddy covariance flux and C_T^2 measurements.

E.2.3.2 Reference-crop evapotranspiration ET0 from satellite images

In a simplified form the FAO guideline for computing crop water requirements reads as:

$$ETC = Kc\ ET0\,, \tag{2}$$

where ET0 is the reference-crop evapotranspiration, ETC is the water requirement of the agricultural crop of interest that is assumed to grow under optimum conditions, e.g. it does not suffer water stress, and K_C is a crop-factor. ET0 refers to the evapotranspiration of a (hypothetical) grass field that has a prescribed albedo and roughness length and grows in large well-watered fields (no water stress). According to the FAO-guidelines ET0 is evaluated with a special version of the Penman-Monteith equation using the measured air temperature, humidity and wind speed over the reference crop, i.e. well-watered grass. In addition the incoming solar radiation is needed.

Maintenance of ET0 stations is costly and requires well-trained staff. In particular in semi-arid countries it is difficult to grow and maintain well-watered grass according to the FAO definition. Consequently, the number of high quality ET0-stations is small, in particular in those countries where water is scarce and food production highly depends on irrigation. Several studies, in which Dr. Henk De Bruin was involved, have revealed that a simple radiation based method can provide reliable ET0 estimates. Besides the air temperature, these equations require either the incoming shortwave radiation or net radiation. It has been shown that, in its turn, the incoming shortwave radiation can be determined from geostationary satellites, in particular the European satellite MSG. Recently, MSG derived incoming solar radiation became available for most regions around the Mediterranean through LANDSAF project (http://landsaf.meteo.pt). The objective of LANDSAF is to develop operational products related to surface-atmosphere processes from Meteosat Second Generation (MSG) satellite images. In the context of IRRIMED WU has investigated the applicability of this product as an operational tool in irrigation water management. WU ahs been in contact with the LANDSAF group in the framework of IRRIMED and a collaboration has been established with the objective to include ET0 as a standard LANDSAF product. This work is still in progress. It will be continued in a next EU-project.

E.2.3.3 Determination of crop factors in the Jordan Valley with Eddy Correlation

During the first work visit of Dr. Henk De Bruin and Oscar Hartogensis to Jordan in September 2003 it was decided that given the interest of the University of Jordan (UoJ) in estimating crop factors (see Equation 1) and the fact that the fields in the Jordan valley are rather small, UoJ was best of in deploying eddy-correlation systems rather then the planned scintillometers to estimate fluxes.

WU sent their EC-equipment to Jordan and Mr. Hartogensis of WU assisted Mr. Jitan and his staff with the installation of the equipment over alfalfa at the research station of the UoJ in December 2003. Mr. Hartogensis gave a training course on details of the eddy correlation method and used written material for this purpose. In February 2004, Mr. Hartogensis came over to de-install the equipment and ship it back to Wageningen. Between December and February one growing cycle of alfalfas was completed.

In the mean time NCARTT received the EC equipment received the EC equipment they ordered and continued subsequent series of the same type of experiments covering one growing season of tomatoes, sweet-corn, potatoes and cauliflower at the NCARTT research station. The crop factors determined from the EC data were compared with the values given by FAO for alfalfa. In general, the EC values appear to be lower than the FAO ones.

An outcome of the successful cooperation between WU and UoJ was the finalization of the PhD by Mr. Jitan, which is based on the eddy-correlation measurements we performed in the Jordan Valley.

E.2.3.4 Kamech catchment site, Tunisia

This field experiment concerns a small hydrological watershed named Kamach. It is located in the Cap Bon region, Tunisia and has an area of in 2,45 km^2. A scintillometer and two EC systems are installed in this catchment to monitor the evapotranspiration. WU has not been involved in the installation of this equipment, but is assisting in the interpretation of the EC data. The main challenge in this catchment in interpreting the fluxes is the topography, which is very pronounced for EC measurements (slopes of ~ 20°). The only sensible way to deal with EC data gathered in such terrain is by performing a co-ordinate transformation of the raw measurements defined by the so-called planar-fir, where the data is fitted to a plane through the average flow field, thereby aligning it with the sloped surface. WU trained the Tunisian group in using the EC-pack program developed at WU, which incorporates the planar fit correction and assisted them in interpreting the results.

E.2.3.5 XLAS experiment near Toulouse, France

The goal of the experiment was to assess the applicability of an eXtra Large Aperture Scintillometer (XLAS) in combination with Meteosat Second Generation (MSG) images to estimate regional evapotranspiration of heterogeneous terrain on scales of 10-100 km^2. Originally, this was experiment was planned to be performed in Morocco, but for practical reasons (lack of high towers/hills over a distance of ~10km) was moved to the south of France, which with its Mediterranean (sea) climate is also part of the IRIMED project area. In collaboration with Joost Hoedjes, PhD student at CESBIO, the XLAS was installed south of Toulouse between two high points in the villages Muret and Lherm overlooking a valley where the land use is mainly agricultural. The crops grown were in part irrigated. The XLAS transmitter was installed in a GSM tower situated on top of a hill in Muret. Following the method described by Hartogensis et al. (2003), the effective scintillometer height was estimated as 45 m. The experiment ran between June 2005 and March 2006.

The XLAS is an optical instrument consisting of a transmitter and receiver that measures the intensity fluctuations of the transmitted light-beam along the line of sight. These fluctuations are related to the structure parameter of the refractive index, C_n^2, which is the principle physical parameter that is determined with this type of scintillometers. From C_n^2 the sensible heat flux can be determined following Monin-Obukhov similarity theory. A limiting factor in the application of the scintillometers is that the level of intensity fluctuations has a maximum value above which the instrument saturates, i.e. additional intensity fluctuations are no longer registered. Saturation occurs sooner at lower measurement height, longer path length and smaller beam diameter.

The XLAS near Toulouse had a path length of almost 10 km (9.62 km) at a height of 45 m. Recently, Kohsiek et al. (2006) showed that for these path lengths saturation effects still can be important and compare two correction methods described in the literature. These corrections adjust the value of C_n^2, as is described in the third year annual report, where the basic outline of one of these correction methods is given.

Figure 3 shows the saturation effect on the sensible heat flux, *H*., which shows that the error in *H* due to saturation amounts to ~ 15% error in *H*.

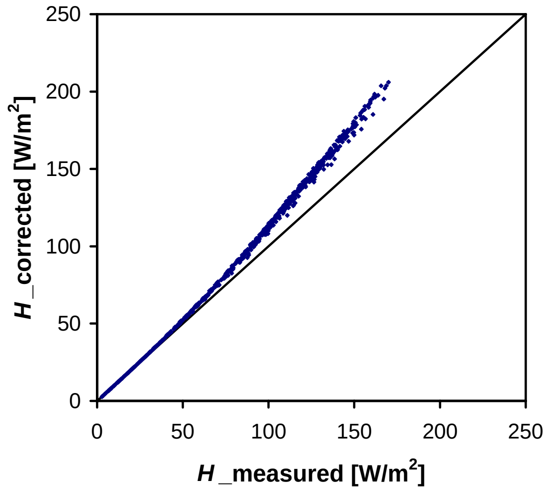


Figure 3: The measured sensible heat-flux, *H*_measured, based on the measured C_n^2 which is affected by saturation against *H*_corrected, which is based on the saturation corrected C_n^2.

To further simplify the saturation correction we found the following empirical function between the corrected and non-corrected *H* depicted in Figure 2:

$$H_{satcor\_fit} = H_{meas} + \left[G(C^2_{n,OBS}) + F(U) \right], \qquad (3)$$

where

$$F(U) = \frac{2.5}{3} U - 2.5 \text{, and}$$

$$G(C_n^2) = 0.6729 + 0.207 C^2_{n\ meas} + 0.6052 \left[C^2_{n\ meas} \right]^2 - 0.0147 \left[C^2_{n\ meas} \right]^3$$

are fit functions that describe the difference between saturation corrected *H* and measured *H* without correction. Note that this empirical correction contains the same ingredients as the multi-variate regression to the full correction, i.e. $C^2_{n,OBS}$ and l_0 , which is a function of wind speed and is represented by $F(U)$. As shown in the third year annual report this simple approach works very well.

E.2.3.6 Advection effect on *ET* of irrigated crops

WU analyzed an existing micrometeorological data set collected over irrigated alfalfa to investigate the effects of advection on *ET* under conditions where advection causes negative sensible heat flux the entire day (De Bruin et al., 2004). The data were collected during the RAPID (Regional Advection Perturbations in an Irrigated Desert) field experiment in Idaho, USA in 1999. It is recalled that the IRRIMED field experiment in Jordan concerns alfalfa also. The results have been included in the lecture notes for the Palmyra IRRIMED Workshop on actual evapotranspiration. It appears that advection enhances actual evapotranspiration of alfalfa significantly at high wind speeds. During nighttime actual evapotranspiration of alfalfa can be significant under high wind speed conditions. These findings suggest that alfalfa is not a suitable crop in dry windy regions where water is scarce. During the discussions at Palmyra, Dr. Brunel of ACSAD showed data gathered over the Palmyra oasis revealing that the actual evapotranspiration of the crops growing there tends to close their stomata at high wind speed conditions.

In addition the application of two types of scintillometers were considered, notably a displaced beam small aperture laser scintillometer and the large aperture scintillometer (LAS). The scintillometer data were not analyzed before. It was concluded that both scintillometer systems, in combination with net radiation and soil heat flux measurements, are useful to estimate operationally evapotranspiration also under advective conditions. Advantages of the scintillometer over the EC-method are that scintillometers are robust and simple to operate, the scintillometer components can be installed at the border a field avoiding interference with the farmer's activities, and the scintillometer footprint is better defined than that of EC measurements. These results were published in an extended abstract for an international conference at Copenhagen in June, 2006 (Hartogensis and De Bruin, 2006).

E.2.4 Publications

DeBruin, H.A.R., 2004: Actual Evapotranspiration, lecture notes IRRIMED Workshop on Actual Evapotranspiration, Palmyra, February 2004.

De Bruin, H.A.R. , 2004: Various CAL (computer aided learning) modules for the IRRIMED Workshop on Actual Evapotranspiration, Palmyra, February 2004.

De Bruin, H.A.R., Hartogensis, O.K., Allen, R.G., and Kramer, J.W.J.L., 2005: 'Regional Advection Perturbations in an Irrigated Desert (RAPID) Experiment', *Theor. Appl. Climatol.* **80**, 143-152.

De Bruin, H.A.R., and Hartogensis, O.K., 2005: 'Variance method to determine fluxes of momentum and sensible heat in the stable atmospheric surface layer', *Boundary-Layer Meteorol.*, **116**, 385-392.

Hartogensis, O.K., Watts, C.J., Rodriguez, J.-C., De Bruin, H.A.R.: 2003, 'Derivation of the effective height for scintillometers: La Poza experiment in Northwest Mexico', *J. Hydrometeorol.* **4**, 915-928

Hartogensis, O.K. and De Bruin, H.A.R., 2005: 'Monin-Obukhov similarity functions of the structure parameter of temperature and TKE dissipation rate in the Stable Boundary Layer', *Boundary-Layer Meteorol.,* **116**, 253-276.

Hartogensis, O.K.: 2006, '*Exploring Scintillometry in the Stable Atmospheric Surface Layer*', Ph.D. thesis Wageningen University, Wageningen, Netherlands, 227p. (ISBN 90 8504 368 9).

Hartogensis, O.K. and H.A.R. De Bruin, 2006: *Estimating surface fluxes in irrigated areas with scintillometers*. In: Proceedings Computational Methods in Water Resources XVI International Conference: Copenhagen, Denmark. CMWR (2006)

Jia, L.; Hurk, B. van den; Menenti, M.; Moene, A.F.; DeBruin, H.A.R.; Baselga Yrisarry, J.; Ibanez, M.; Cuesta, A., 2003: *Estimation of sensible heat flux using the Surface Energy Balance System (SEBS) and ATSR measurements.* Physics and Chemistry of the Earth 28, 75-88.

Kohsiek, W., Meijninger, W.M.L. De Bruin, H.A.R. and F. Beyrich, 2006: 'Saturation of the Large Aperture Scintillometer', Boundary-Layer Meteorol., DOI 10.1007/s10546-005-9031-7

Van Den Bersselaar, D., 2003: *Surface flux estimates over an olive yard: Eddy covariance and Scintillometer method.* MSc-thesis, Wageningen University, Wageningen, Netherlands, 49 pp

Van Den Kroonenberg, D., 2003: *Surface flux estimates over an olive yard: SEBAL method applied to NOAA-KLM and Landsat-7.* MSc-thesis, Wageningen University, Wageningen, Netherlands, 66 pp

Williams, D.G., Cable, W., Hultine, K., Hoedjes, J.C.B., Yepez, E., Simonneaux, V., Er-Raki, S., Boulet, G., De Bruin, H.A.R., Chehbouni, A., Hartogensis, O.K. and Timouk, F., 2004: 'Components of evapotranspiration determined by eddy covariance, sap flow and stable isotope techniques', *Agricultural and Forest Meteorology* **125**, 241-258.

E.2.5 Conclusions

All the objectives formulated in WP2, where all activities of WU resort to have been met. Especially the micrometeorology courses have been a good investment of resources, which have resorted in a very effective increase of knowledge of the PhD students involved in the projects. Thanks to that knowledge gained, many of them they are currently in the process of finishing their projects (see WP2 report).

In addition a number of science topics have been dealt with in the framework of IRRIMED such as: application of remote sensing to estimate ET0, evaluation of the saturation effect of scintillometers, the application of scintillometers over tall vegetation involving an adjusted displacement height formulation, the determination of crop factors by eddy-correlation in the Jordan Valley, the application of the eddy correlation over sloping terrain, and the effect of advection on *ET* and the application of scintillometers under such conditions. Some of these topics have been presented as conference papers, others are in the process of publication in a peer reviewed international journal.

E.3 Report of partner 3
(Faculty. of Agriculture, University of Jordan)

Prepared by: Feras Ziadat

Project Objective

As a reminder, the **general** scientific objective of IRRIMED is the assessment of temporal and spatial variability of water consumption of irrigated agriculture under limited water resources condition.
The **specific** objectives of IRRIMED are:

- Accurate assessment of actual ETR over selected crop during the growing season, allowing to validate models and to update the crop calendar and crop water requirements
- Remote sensing of crop extension and evolution during the growing season, to measure the actual acreages of the different crops
- Refining existing methods for simple ETR estimation, to apply them spatially, deriving ETR maps from satellite data

The expected **deliverables**, as explained in the technical annex, from workpackage 1 are as follow:

1. Digital information layers (in a commonly agreed format) on the permanent features of the agricultural environment (geology, soils, boundaries,
2. Ready to be used (pre-processed) low and high resolution Spot4 and 5 satellite image sets
3. Global land use / land cover map of the test sites
4. Monthly map of extent of irrigation areas
5. Crop identification and growing stage (NDVI) on selected area (zooming in)
6. Building blocks of a global information system on the test site (in conjunction with WP5)

The work described here fits within the above deliverables to achieve the objectives of this workpackage. The first part listing the specific contributions of partner 3 to workpackages, while later sections represent scientific report following the commission formats.

E.3.1 Part One: list of specific contributions of partner 3 to all workpackages

Contribution to workpackage 1

- Building the background information system on the environment of each test site: The following information were collected and compiled from various sources: climate; geology; soil data; topography; administrative boundaries; DEM; high and low resolution satellite images. To facilitate the harmonization and exchange of data, ArcView software was recommended for vector files (GIS) and ENVI software for raster files (remote sensing).
- Acquisition of ground information: Permanent reference points for accurate georeferencing (base map SPOT, 2m spatial resolution).
- Ground truth for land cover /land use mapping was collected both as point data and based on farm units.
- Ground truth for calibration and normalization of satellite images using CROPSCAN.
- Ground truth for crop type identification using SPOT time series images.
- Building the satellite derived information: develop the crop inventory using the special set of SPOT high and very high resolution that has been ordered by CESBIO from the CNES. Combining it with ground collected data, different classification techniques (visual interpretations, supervised and unsupervised classifications) were refined to obtain high-resolution ‘per field’ crop classes.
- Times series of images following the crop development have been acquired over the Jordan Valley through special programms of CNES (12 High resolution SPOT images), with accompanying field data collection. This allowed the refinement of crop identification (including greenhouses). The conversion into ground reflectance hallowed the use of these images to compute ET for some selected crops, testing spatialization techniques for the Jordan case.

Contribution to workpackage 2

- Supply researchers with background information (explained above).
- Supervising Ph.D. student to undertake research related to workpackage 2. JITAN, M. (2005): “Evapotranspiration of major crops in the Jordan Valley using Remote Sensing techniques compared with estimated field measurement using Eddy-Correlation”.

Contribution to workpackage 4

- Providing background information, particularly on irrigated/non-irrigated areas and global land cover / land use maps.
- Analyzing SPOT images time series and collection of ground data to identify individual crops to provide information about actual crop development using satellite data.

Contribution to workpackage 6

- Providing data and presentations to endusers to achieve better management of the limited water resources by providing remote sensing based approaches, these includes:
    - Crop types identifications using single image or series of images and by implementing various image processing techniques.
    - Better information to achieve crop monitoring (crop calendar) to facilitate the spatialization of the estimated Etc under local conditions.
- Participation on workshops with the endusers to aid the explanation of research results and to facilitate the implementation of these results based on endusers assessment and comments.

Contribution to workpackage 7

- Hosting and organizing workshop for young scientists entitled “Satellite Images Processing for Irrigation Monitoring”.
- Participating in other workshops and activities held on other countries.
- Undertaking many exchange visits to strengthen the regional networking and knowledge sharing.

Contribution to workpackage 8

- Attending all annual project meetings to explain progress and to plan for the future.
- Providing information to build and enrich the project website to facilitate results dissemination and communication within and outside the project.

E.3.2 Part Two: scientific report following the format requested by the commission

This part summarizes the activities achieved by partner 3 (University of Jordan). The specific contribution of these activities to different project workpackages was explained in part one.

E.3.2.1 Objectives

To harmonize and to bring together under the appropriate format the whole data set needed for the project for each of test site. This includes: collecting existing background data on topography, soil, climate; acquisition of new data on the ground (including met.) and from satellite (low and high resolution), processing them to obtain maps of irrigated plots extensions, main types of crops, crop calendar. Data will be handled with GIS software common to all participants.

E.3.2.2 Activities

The following major activities were achieved:

1. Building the information system
2. Global land use / land cover map
3. Linking crop coefficient with NDVI
4. Crop identification and growing stages (time series)

For each activity the following aspects will be explained: methodology, results achieved, problems encountered, and technology implementation plan.

E.3.2.2.1 Activity One: Building the information system

Methodology

The following information were collected and compiled from various sources. To facilitate the exchange of data and the establishment of common procedure to input data into the models, ArcView software was recommended for vector files (GIS) and ENVI software for raster files (remote sensing).

Climate: The following information regarding the climate were collected: Karamah, Deir Alla, and Wadi al-Yabis weather stations, from (June, 2000) onwards:

- Daily Climatic Data (average, maximum and minimum): air temperature (ºC), solar radiation (w m^{-2}), relative humidity (%),pressure (mb), wind speed (m s^{-1}), wind direction, total rainfall (mm), leaf wetness fraction (day).
- Daily Evapo-transpiration
- General information about the climate in Jordan.
- Agro-meteorological data for seven stations, Baqura, Deir Alla, Ghor Safi, Irbed, Rabba, Shoubak and Wadi Dhuleil. Some of these stations are located inside the study area of IRRIMED.
- Graphs that represent water balance (monthly mean evapotranspiration (mm) and monthly mean rainfall (mm)) for Jordan rift valley, and Deir Alla.
- Agro-climatic zones of the Jordan Valley according to the MOW classification (Northern and Southern Jordan Valley).

Geology: a map that shows the classification according to the life era was obtained for the whole country. More detailed map was obtained for the IRRIMED study area from MOW, the map shows the following formations: RIJAM, ALLUVIUM, MUWAQQAR, AMMAN/WADI SIR, LOWER AJLUN, KURNUB, ZARQA GROUP.

Soil data: Level one soil map (scale 1:250,000) covers the study area was obtained. Soil observations taken during the soil survey are also available.

Topography: a general map that shows the elevation levels for the whole country was obtained. In addition, more detailed topographic information for the IRRIMED study area was obtained from MOW: contour lines (100m vertical intervals); wadi network; villages (polygon features); road network; King Abdullah Canal; Jordan river; general land use map (included classes: forest, orchard, brush, and build-up area).

Administrative boundary: a map that shows the administrative boundary (Sub-Districts) for the whole country was obtained. More detailed maps for the IRRIMED study area were obtained from MOW. These represent the subdivisions within the Jordan Valley Authority (JVA) Mandate area. These include: JVA mandate area; development areas; stage offices; farm units. These are important management units for the JVA.

Digital Elevation Model (DEM): A digital elevation model covering the IRRIMED study area was obtained from ASTER. The resolution is 30 m and the area was covered using two frames (center point: 32.00 Lat / 35.79 Lon and 32.59 Lat / 35.53 Lon).

High-resolution image (base map): Panchromatic SPOT image (2.5 m resolution) was geometrically corrected using ground control points. This image was used as a base map to geo-reference any information to get the best harmonization in all project information.

- **Results achieved**

This activity was necessary to serve other project activities, and therefore the results mainly benefited the project implementation. The main outcome of this activity is a digital database, which encompass all necessary information for modeling of water management in the study area, which served the project activities. The data is harmonized in terms of format, georeferencing and other aspects.

- **Problems encountered**

Geographic information in Jordan is registered using many projection and coordinate systems (to mention some: Jordan Transverse Mercator (JTM), Universal Transverse Mercator (UTM), Cassini (Palestine Grid or Belt)). Each of these is using certain datum and spheroid, which complicate the harmonization of data from different sources. One way to deal with this was the accurate registration of high-resolution SPOT image (2.5 m) using ground control points, and the subsequent registration of all other data to this base map. This represent starting point to get accurately geo-referenced information to serve water management activities.

- **Technology implementation plan**

It is anticipated that future activities in the MWI would rely on such database to improve the management of water resources.

E.3.2.2.2 Activity Two: Global land use / land cover map

- **Summary and Objectives**

Knowledge about the area of each crop and consequently the variability in the monthly water demands are indispensable to achieve an optimum water allocation management in extensively irrigated areas. Currently the Jordan Valley Authority (JVA) relies on field surveys to get this information. An alternative approach is the use of remote sensing images. The main objective of this activity was to provide reliable information about the area and distribution of different crops that are cultivated in the Jordan Valley.

- **Methodology**

Two SPOT images were utilized to undertake this study, one PAN image (one band) with spatial resolution of 2.5m, and another multi-spectral image (4 bands) with spatial resolution of 10m. A subset was taken from each image to represent the study area. A total of 35 ground control points (GCP) were collected from the field using GPS (± 3m accuracy) and were used to geo-reference the 2.5 m resolution image. The 1st degree polynomial warp method and cubic convolution re-sampling method were used. The RMSE for the registration was 2.4m, which is less than one pixel. The 10m-resolution image was geo-referenced using image-to-image correction from the 2.5m geo-referenced image. The recorded RMSE was 9.92m, which is again less than 1 pixel.

The two images were merged together using Gran-Schmidt algorithm (in ENVI software). The result is an image with spatial resolution of 2.5 m and spectral resolution of the 4 bands taken from the 10m-resolution image. The 10m-resolution image was used to undertake the supervised and unsupervised classifications trails, while the merged image was used to undertake the visual image interpretation process. The actual crop types that are cultivated in each farm were derived from field observations (142 fields) and from the Jordan Valley Authority records (1472 farm units).

After gaining some experience regarding the pattern, shape and reflectance of each crop, the visual interpretation was accomplished for the whole area. The accuracy of the visual interpretation was assessed using the JVA data. A first trail to undertake the unsupervised classification was implemented using the same number of classes used for the visual interpretation (9 classes). The ISO data classification algorithm was used in the ENVI software. The results of this classification were compared with the visual interpretation results visually (through maps overlay) and quantitatively (percent of area correctly classified). The supervised classification was undertaken using maximum likelihood algorithm. Two data sets were used to extract data to train the classifier, the visual interpretation results and the JVA records (1472 farm units).

The preliminary results of the supervised classification indicated low accuracy of identifying crops. The main reason was the use of the whole farm unit (many heterogeneous pixels) to train the classifier. Alternatively, smaller area within each farm (includes fewer pixels) were used.

- **Results achieved**

Visual interpretation: The agreement between crops identified by visual interpretation with those recorded by the JVA is indicated in table (1). This comparison included farm units that are occupied by one crop in both JVA records and visual interpretation results. The overall agreement (86%) indicated good achievement using the visual interpretation method.

Table 1: Agreement between visual interpretation and field record of crop types.

E.3.2.3.1 Visual interpretation	**E.3.2.3 MWI records** Trees	Annual crops	Alfalfa
Trees	**1039**	133	1
Annual crops	78	**389**	5
Alfalfa	0	0	**15**
Greenhouses	3	**17**	1
Fallow	9	**20**	0
Water Bodies	0	0	0
Unknown	0	0	0
Urban	0	0	0
Others (canal, street)	6	7	0
Overall Agreement = 1480 / 1722 = 86%			

Note: greenhouses and fallow were considered as annual crops.

This result encourages the implementation of visual interpretation procedure to identify the general land cover classes in the area. Given the high cost and time required for field surveys to collect such data, the visual interpretation of satellite image provides a practical solution. Furthermore, in some cases the interpretation of the image highlighted some benefits over the field survey technique. Particularly in identifying the actual land use in those farm units occupied with more than one crop. Figure (3) shows two examples where the JVA indicated one crop for the farms within the white line (boundaries of the farm unit), while the image shows obviously that the farms are occupied by two crops (separated by the blue line).

The visual interpretation indicated acceptable results in terms of identifying crops but under the nine groups mentioned in table (1). However, for effective water management it is necessary to identify individual crop types (to identify crop water requirement). Using the satellite images, even with the best available resolutions (2.5 m), indicated that the individual crop types could not be identified visually. The best option was the amalgamation of crops in the 9 classes mentioned in table (1). Therefore it was necessary to investigate the utility of different techniques (unsupervised and supervised classifications) to improve the capability of satellite images to achieve better identification of individual crop types.

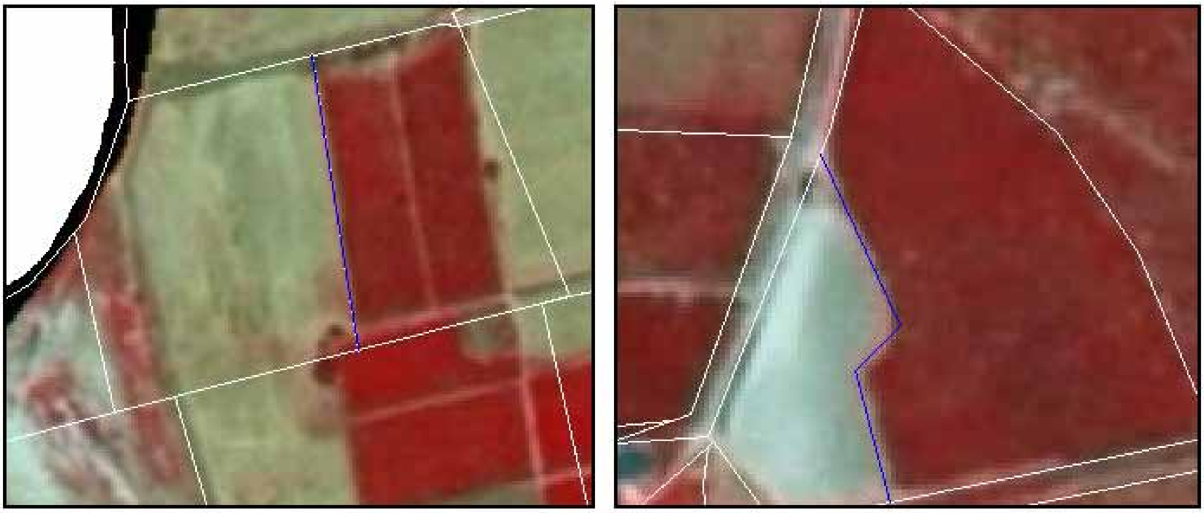


Figure 3: Examples where satellite image might help in identifying the crops that are cultivated within one farm unit.

Unsupervised classification: The preliminary quantitative comparison between the results of unsupervised classification and visual interpretation results indicated that two classes were identified using the former, these are tree and annual crops. The rest of the area was classified into different classes but the identification of these classes was difficult (scattered pixels without distinguishable pattern). The visual comparison indicated the weak capability of the unsupervised classification to cope with the large heterogeneity of pixels within one farm that is actually cultivated with one crop. This indicates low capability of this method to aid the process of land cover identification. No further trails were tested to improve the results. More investigations were directed to try the possibility of using supervised classification procedure.

Supervised classification: The first comparison includes the use of crops amalgamated into three groups (trees, annual crops and alfalfa). The results in table (2) indicated an overall accuracy of 77.5% (when small training area was used). This indicates that the use of fewer pixels within one farm unit to train the classifier would result in more confident and consequently better classification. The results indicated high confusion between both tree and annual crops with alfalfa. The overall accuracy of the classification was increased to 86.2% when alfalfa was excluded from the classification.

Table 2: Agreement between supervised classification results and JVA records for groups of crops using small area within the whole farm to train the classifier.

Supervised Classification	JVA records (field survey)		
	Trees	Annual crops	Alfalfa
Unclassified	2.7	9.0	0.0
Trees	**78.8**	8.6	37.3
Annual crops	8.1	**69.7**	30.5
Alfalfa	10.4	12.7	**32.2**

The overall accuracy of the supervised classification to identify individual crops was generally low (48.7%). The best utility of the supervised classification is therefore to separate group of crops (trees from annual crops) and preferably without considering alfalfa (masking the alfalfa fields). This accuracy is comparable with the accuracy resulted from using visual interpretation to identify groups of crop types. The low accuracy of supervised classification to identify individual crops indicated the need to suggest alternative methods. Two approaches were highlighted as alternatives. First, regroup the crops according to other criteria, such as the crop water requirements. Second, investigate the utility of a time series of satellite images. The first approach is explained in the following paragraphs while the second is explained under activity number four.

The crops were grouped according to their similarity in terms of crop water requirements into the following five groups: orchards; banana; vegetables; field crops; alfalfa. The overall accuracy of the classification was 72.7%, which is much better than considering the crops individually (48.7%). These results indicated a good improvement in the identification of these groups of crops. For the purposes of planning water resources the information provided by this method might be useful. Comparing this method with field surveys is required to make decision about implementing this approach by the JVA.

- **Problems encountered**

The major difficulty faced this investigations is the small size of farm units in the JVA area. This is an important aspect when satellite data was introduced. However, the study was successful in providing various technical alternatives to map crop types, as individual or grouped, especially tailor-made for the study area.

- **Technology implementation plan**

The results of this study indicated that satellite image could be used successfully to identify cropping pattern in an intensively irrigated area. The required level of accuracy and purpose of using the results determine the optimum procedure. Visual interpretation produce an acceptable results in separating crops, but only as group (trees, annual crops, alfalfa). The other possibility is the supervised classification using groups of crops based on their water requirements. This provides an opportunity to generate map for the crops cultivated with minimum fieldwork and, more importantly during the growing season. This will help in better management and allocation of water resources during the season. Furthermore, this layer of information, together with an estimate of the actual water requirements for each group could be used to derive a map that shows the spatial distribution of various crops and various water demands over the Jordan valley.

E.3.2.3.2 Activity Three: Linking Crop Coefficient with NDVI

- **Methodology**

The alfalfa field is located in the Jordan valley at the University of Jordan experimental station, where measurements of the Actual ET using Eddy correlation instrument during the period 15th December 2003 to 15th February 2004 were taken. The idea of taking CROPSCAN measurements in this field is to try to establish relationship between Kc (estimated from the Eddy) and the Normalized Difference Vegetation Index NDVI (measured by the CROPSCAN). A number of points were selected within the field and CROPSCAN measurement was taken at each point. The field is rectangular with width of 125m and a length of 560m. A grid of approximately 30m was used for the sampling procedure. The exact location of each point was determined using GPS. Similar sampling strategy was followed at each date when new measurement was taken.

- **Results achieved**

The results indicated a consistent and uniform increase in the NDVI values as the crop is progressing in the growth stages. A comparison was undertaken between the NDVI values and the Kc values estimated using the Eddy correlation method for the same growing period. The results indicate a relatively consistent relationship between NDVI and Kc for the alfalfa field, with a regression coefficient (R^2) equal to 0.79. These results are promising in terms of establishing a solid relationship between ground measurements of crop coefficient (Kc) in one hand and remote sensing derived parameters (NDVI) on the other hand.

- **Problems encountered**

More fields and longer time was required to verify and strengthen the above relationships. However, these preliminary results would be a good starting point for further research.

- **Technology implementation plan**

The results will be useful for the identification of areas with different water requirements, which is important for water management. The satellite image will provide the extent of water requirements over the JVA. However, further investigation for other crops is still needed to implement these findings.

E.3.2.3.3 Activity Four: Crop identification and growing stages (time series)

- **Methodology**

SPOT Images: A series of 12 SPOT images (10m resolution, 4 spectral bands) were acquired through special programs of CNES (French Space Agency) over the IRRIMED study area during the period between 23/10/2005 and 25/06/2006 (figure 1). The exact dates of acquiring each image are shown in figure (1). These images were geometrically and radio-metrically corrected.

Measurement of surface reflectance (certain crops): A number of fields were selected to measure the surface reflectance of the cultivated crops using hand-held radiometer (Multi-spectral Radiometer System by CROPSCAN, INC.). For each field, a number of CROPSCAN readings were taken at different dates (table 3). The monitored crops are (important and dominant crops in JVA area): Forage crop (Alfalfa); Potato; Lettuce; Broad Beans; Tomato; Onion; Carrot; Crucifers; Squash; Mallow; Corn; Eggplant; Okra. In addition, a number of *invariant* areas (fields) were also monitored to enable the normalization of the images.

Identification of cultivated crops: A number of fields were selected over the study area to identify the type of crops that are cultivated in each. For each field the location (using GPS), the type of crop cultivated, and the cultivation and harvesting dates were recorded. The sampled crops were: alfalfa; banana; broad beans; beans; carrot; citrus; corn; crucifers; date; eggplant; grapes; guava; lettuce; mallow; okra; olive; onion; pepper; potato; squash; tomato; wheat.

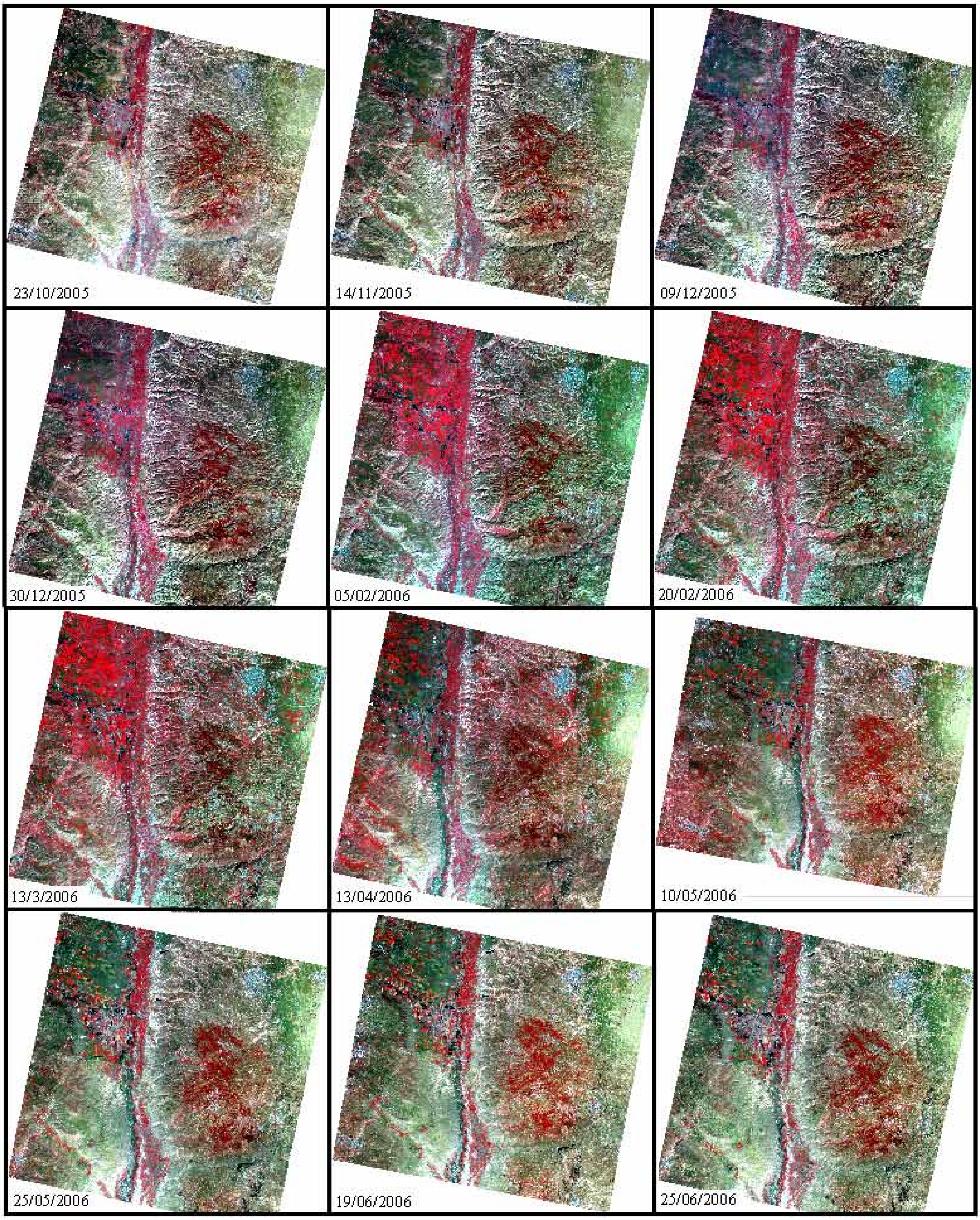


Figure 1: snapshot of all acquired SPOT images.

Table 3: daily rainfall amounts, dates of SPOT images acquired, and dates of CROPSCAN measurements during the 2005/2006 season.

Date	RAINFALL (mm)	SPOT IMAGE	CROPSCAN Reading	Date	RAINFALL (mm)	SPOT IMAGE	CROPSCAN Reading
23/10/2005	0	S1		16/2/2006	1.52		
14/11/2005	0	S2		17/2/2006	0.25		
09/12/2005	0	S3		20/02/2006	0.00	S6	
11/12/2005	0		M1	01/03/2006	0.00		M5
15/12/2005	0		M2	9/3/2006	0.25		
28/12/2005	0		M3	10/3/2006	1.52		
30/12/2005	0	S4		13/3/2006	0.76	S7	
7/1/2006	1.01			1/4/2006	2.54		
8/1/2006	6.35			2/4/2006	67.31		
9/1/2006	0.76			3/4/2006	0.25		
11/1/2006	21.84			5/4/2006	12.95		
12/1/2006	6.60			6/4/2006	2.03		
14/1/2006	0.76			9/4/2006	0.00		M6
15/1/2006	0.51			13/04/2006	0.00	S8	
17/1/2006	5.33			20/04/2006	0.00		M7
18/1/2006	2.03			24/4/2006	10.41		
22/01/2005	0.00		M4	4/27/2006	0.00		M8
26/1/2006	1.27			10/05/2006	0.00	S9	
27/1/2006	3.30			24/05/2006	0.00		Calibration*
28/1/2006	1.02			25/05/2006	0.00	S10	Calibration*
2/2/2006	5.84			30/05/2006	0.00		Calibration*
3/2/2006	5.80			01/06/2006	0.00		M9
05/02/2006	0.00	S5		10/06/2006	0.00	S11	
8/2/2006	3.81			15/06/2006	0.00		M10
9/2/2006	27.69			19/06/2006	0.00		M11
10/2/2006	0.51			25/06/2006	0.00	S12	
14/2/2006	3.56			11/07/2006	0.00		M12
15/2/2006	7.62						

* CROPSCAN readings taken around the date of acquiring programmed SPOT image (25/05/2006).

- **Results achieved**

See results presented with partner 1 in the consolidated report.

- **Problems encountered**

Two uncontrollable factors hindered the exact synchronization between image acquisition and ground measurements. First, the date of image acquisition could not be exactly determined before the actual acquisition because this would require an extremely high cost, and second, it is not possible to take ground measurements in cloudy days. Nevertheless, the ground measurements of CROPSCAN were, in most cases, close enough to the date of image **acquisition (table 3).**

E.3.2.4 Training and Education

The Eddy-Correlation device was installed at the UOJ Agriculture Experimental Station in the Jordan Valley for training purposes for two months (15 December 2003-15 February 2004). The EC device belongs to WUA and it has been barrowed to Jordan for two months. Mr.

Oscar from WUA conducted training for NCARTT and UOJ staff on installation of the device, calibration and measurements.
Training for the UOJ staff and the Ph.D. student on GPS, Arc-View and ENVI softwares.
Visit of Feras Ziadat to Marrakech (at the occasion of a conference February 2004) meeting with IRD and Moroccan partners.
Visit of Feras Ziadat to Marrakech (IRD lab, Faculty of Science Semlalia) in September 2004. Discussion with Vincent Simonneaux, Benoit Duchemin and Ghani Chehbouni regarding remote sensing application in the project and particularly in the Jordanian site. Morocco 2-9/10/2004.
A training workshop "Satellite Images Processing for Irrigation Monitoring', for young scientists was arranged and held at the Faculty of Agriculture, University of Jordan during the period 28th November – 3rd December 2004.
A Ph.D. thesis was successfully defended at 10 th January 2005 by Dr. M. Jitan under the title: "Evapo-transpiration of Major Crops in the Jordan Valley Using Remote Sensing Techniques Compared with Estimated Field Measurement Using Eddy-Correlation". The thesis was supervised by Prof. M. Shatanawi and co-supervised by Dr. Feras Ziadat.
An exchange visit by Feras Ziadat was undertaken to the IRD laboratory in Toulouse / France between 18th and 26th July 2006. During this visit a thorough discussion was made with the scientists working in that laboratory (Particularly, Richard Escadafal and Vincent Simonneaux). The quality of the acquired data was verified and the possible steps to analyze the data were identified.

E.3.2.5 Scientific articles (currently under preparation):

- Utility of multi-temporal ASTER images for crop type identification and irrigation management.
- Mapping of cropping areas using RS data as a tool for improving irrigation water managements in the Jordan Valley.
- Use of time series images for crop identification in the Jordan Valley.

E.4 Final report of partner 4 (NCARTT, Jordan)

Partner: **National Centre for Agriculture Research and Technology Transfer (Partner 4-Assistant contractor for Partner 3)**

Team members that have actively contributed:

Name	Qualifications
Dr. Abed Al-Nabi Fardous	Specialist in water resources and irrigation
Dr. Mohammad A. Jitan	Specialist in water & irrigation management
Dr. Naeem Mazhreh	Specialist in crop evpotranspiration
Eng. Ali Gharaybeh	Agronomist
Ms. Jumana al-Dwiri	Irrigation Engineer / Temporary.
Eng. Shahwan Sakarneh	Irrigation Engineer / Temporary.
Eng. Muna Khalili	Irrigation Engineer / Temporary.

Participation in meetings including training, etc.

Meeting	Date	Participants
Kick-off meeting, Toulouse France	22-23 May 2003	Mr. Mohammad Jitan.
First working visit from WURC team (Dr. H.A.R. de Bruin and Mr. O.K. Hartogensis). Amman, Jordan	15-19 September 2003	Dr. M. Shatanawi. Dr. A. Fardous Dr. F. Ziadat Mr. M. Jitan Ms. Suzan Taha Dr. Naeem Mazahreh
Training on the Eddy Correlation theories, installation and data processing. By Eng. Oscar Hartogensis Amman-Jordan	11–19 December 2003	Mr. M. Jitan Mr. Fakhry Quwzeh Ms. Jumana al-Dwiri Ms. Luna Al-Hadidi
Workshop on estimation of actual evaportranspiration and crop-water requirements. Palmyra-Syria	7-13 February, 2004	Ms. Luna Al-Hadidi
Remote Sensing Image Processing for Irrigation Monitoring: Hands on Training.	28 Nov-2 Dec 2004	Mr. Mohammed A. Jitan Mr. Marwan Sueifan
Annual meeting, Marrakech, Morocco.	13^{th} -17^{th} April 2005	Dr. Mohammed A. Jitan
Workshop on crop water modelling tools. Tunis, Tunisia.	28^{th} November – 2^{nd} December 2005.	Dr. Mohammed A. Jitan

Contributions per work package (and Deliverables) for the active work package.

E.4.1 Contribution under D1-WP2 “Fully validated micrometeorological data sets on selected experimental plots”:

E.4.1.1 UOJ, Jordan Valley Agriculture research station, Alfalfa crop site:

Location: N 32^o 05’ 21.4”

E 035^o 35’ 46.7”

This was an already existing field at this UOJ agricultural station, with an area of about 3 ha. The actual evapotranspiration for this crop had been measured for the duration of two months only, during the period of 15 December 2003 *(DOY=350)* until 15 February 2004 *(DOY=45).* This limited duration is related to the fact that the EC system belongs to Wageningen University, it was not possible to use it in Jordan for longer periods. However the period was sufficient to get a data for one full growing period of this crop (*one cut)*. On the other hand, crop data such as irrigation, crop height, harvesting…etc was obtained from the UOJ staff, and reported. Daily climatic weather data also were obtained for this station to calculate potential evportanspiration according to Penmman-Monteith equation (ETo). The actual evpotranspiration was measured using the EC system of WUC, calculated, and presented (simplified) in the figures below.

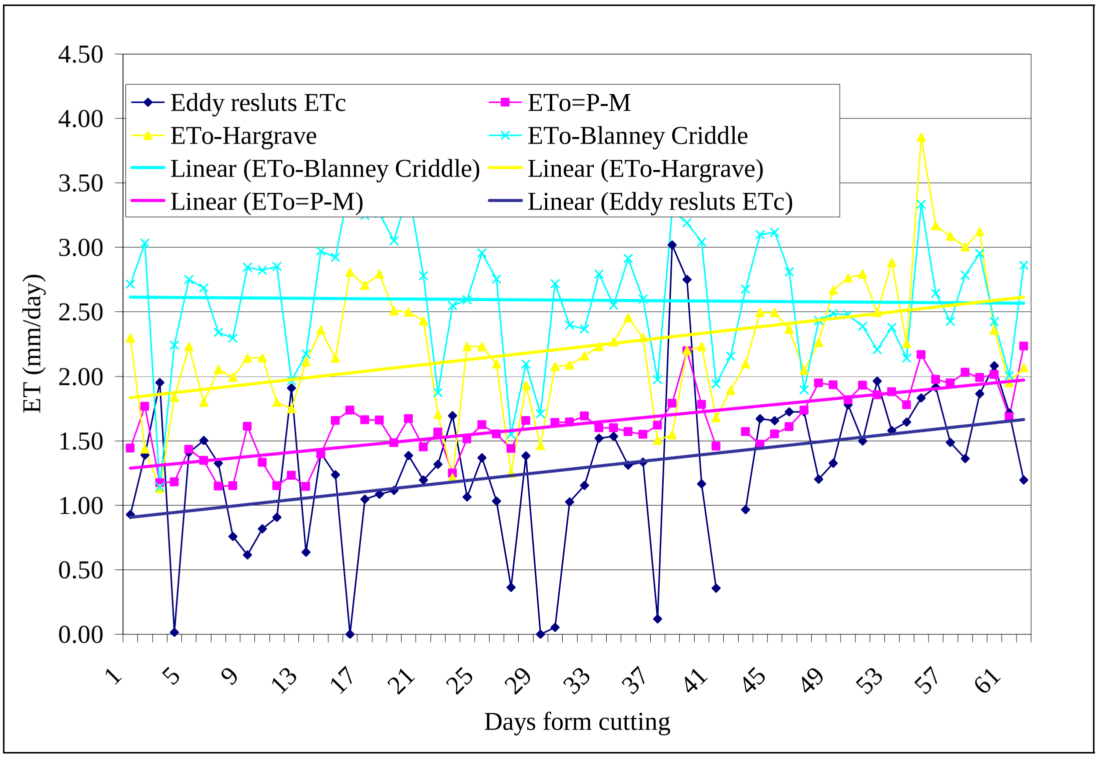


Figure 1: Actual Evapotranspiration on daily basis for Alfalfa crop using Eddy-Correlation method, compared with other ET_O estimation methods.

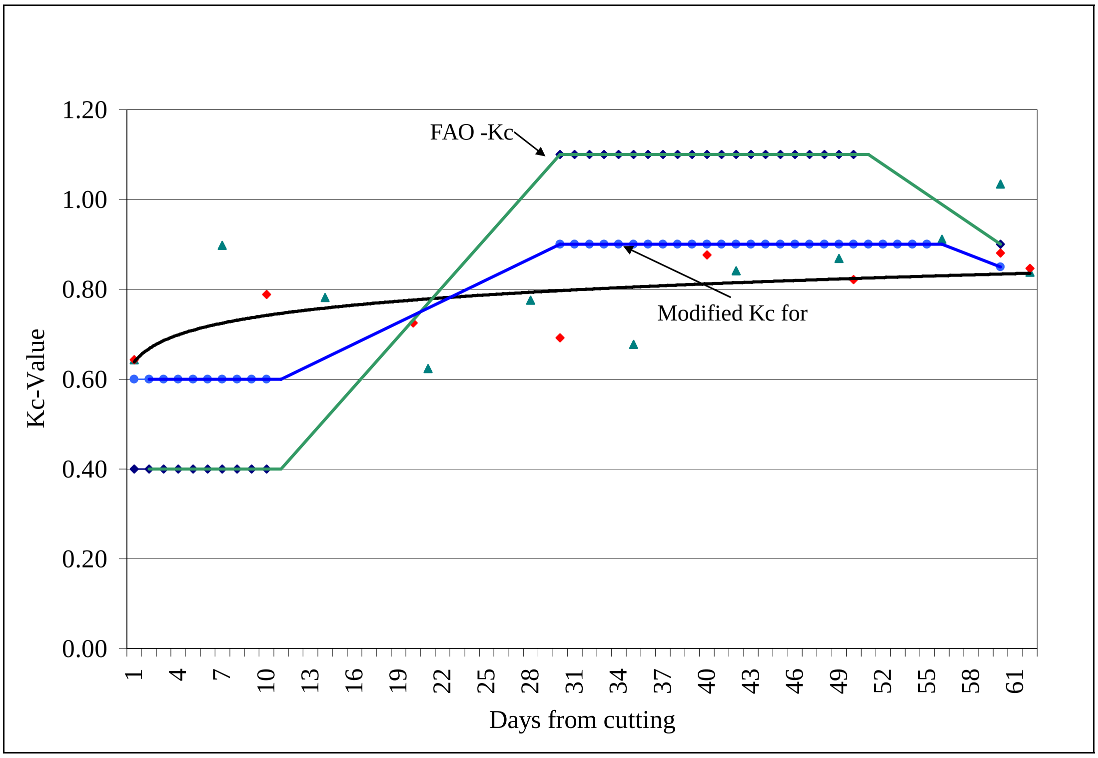


Figure 2 : Modified K_C values for Alfalfa Crop, grown at the University of Jordan research station farm in the Jordan Valley

The Adjusted K_C values for Alfalfa Crop grown in the Jordan Valley are presented in the table below:

Table1 : Adjusted K_C values for Alfalfa Crop grown in the Jordan Valley as compared to FAO-K_C values.

	Adjusted FAO-K_C for Alfalfa crop		**Adjusted K_C for Alfalfa crop grown in the Jordan Valley**	
Crop Stage[1]	Duration (day)	K_C-Value	Duration (day)	K_C-Value
Initial Stage (L_{ini})	10	0.40	10	0.60
Development Stage (L_{dev})	20	1.10	20	0.90
Mid Stage (L_{mid})	20	1.10	25	0.90
Late stage (L_{late})	10	0.90	5	0.85

[1] Allen et. al 1998.

Total	60		60	

E.4.1.2 NCARTT, Dair-Alla experimental station in the Jordan Valley,

Tomato crop site:

Location:* *N 32^o 11' 25.6"
E 035^o 37' 02.1"

At the beginning of the year 2004, NCARTT established an irrigation field with an area of about three ha as shown in figure 3. This field was planted with Tomato Crop *(OSCAR Varity)* between the periods of 4-6th January 2004. During this time NCARTT Eddy Correlation system had been purchased through ARD-France (Dr. Richard Escadafal), and was shipped to Jordan. The cost of this device was 22,736 EU, which was deducted form NCARTT budget. The shipment arrived to NCARTT on 27 January, then it was tested and re-programmed by Eng. Jitan with a direct help from Eng. Hartogensis *(through e-mail).* Then the EC device was immediately installed on 28 January 2004, and readings of actual evapotranspiration started ***(successfully)*** over this tomato filed on the next day.

Crop data (irrigation, fertigation, crop height ..etc) are being collected and reported on weekly basis. The actual evapotranspiration of this site had been obtained starting from 29 January 2004 (DOY=29), the plant is expected to be harvested during the next month (May 2004). At the same time, potential evapotranspiration (ETo) according to Penmann-Monteith equation are obtained form a nearby automatic weather station for NCARTT from the IMIS project, *(only few meters away from the site),* this station provides hourly and daily climatic data (www.ncartt.gov.jo/imis.html).

The actual evapotranspiration of this site were obtained starting from 29 January 2004 (DOY=29) and ended with the plant harvested on June 15 2004 (DOY=167). Total ET_C for tomatoes measured in this experiment is equal to 346mm. While the crop water requirements to be added to the field is equal to 543 mm[2]**.**
The actual evapotranspiration (ET_C) results were obtained on half hourly basis as shown in Figures 4, 5, and 6.

[2] CWR=ETc/[(1-Lf) X I_{eff}%]= 543 mm.

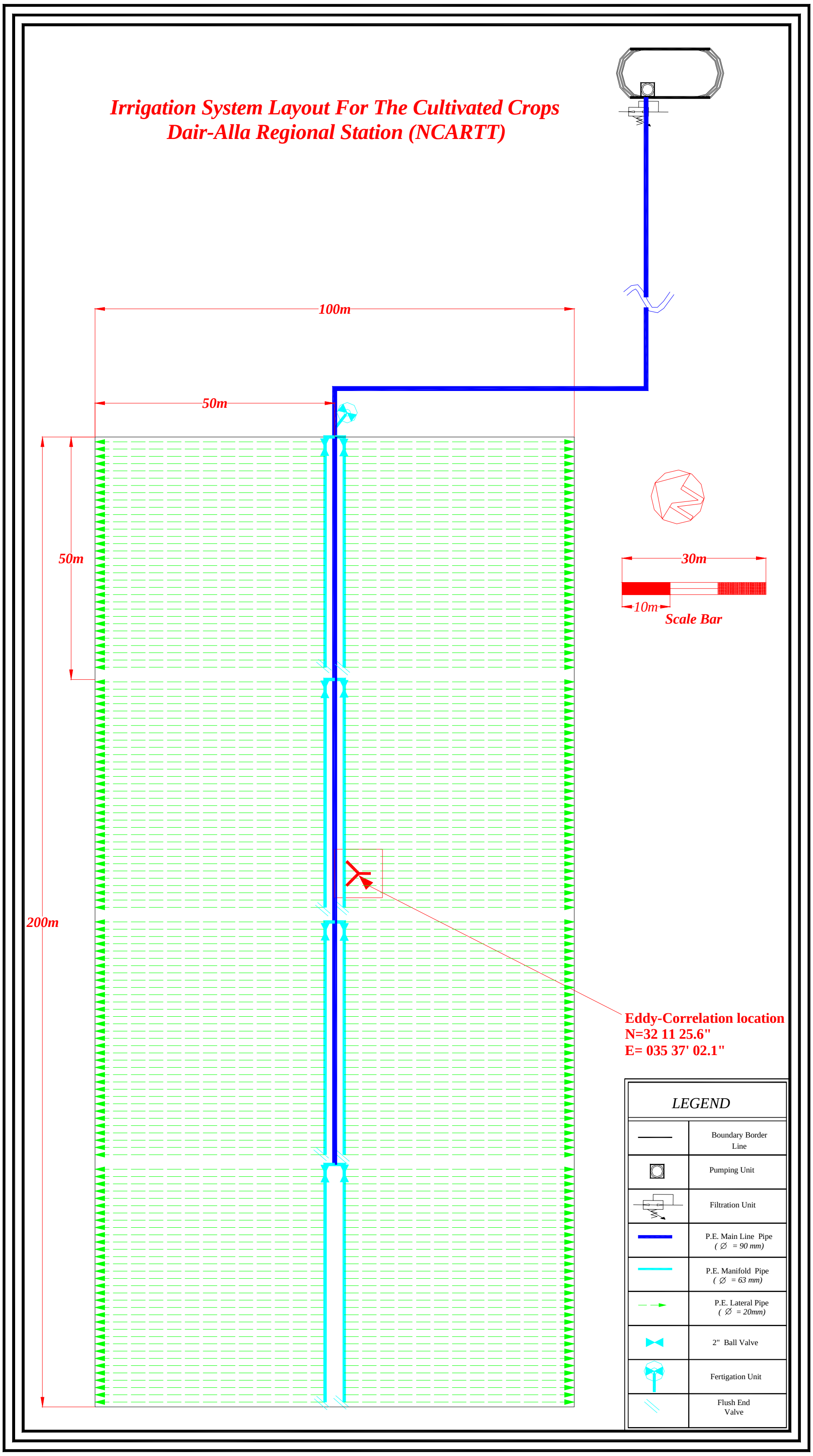


Figure 3: Layout of the irrigation system used for the crops planted in the Jordan Valley at NCARTT Station.

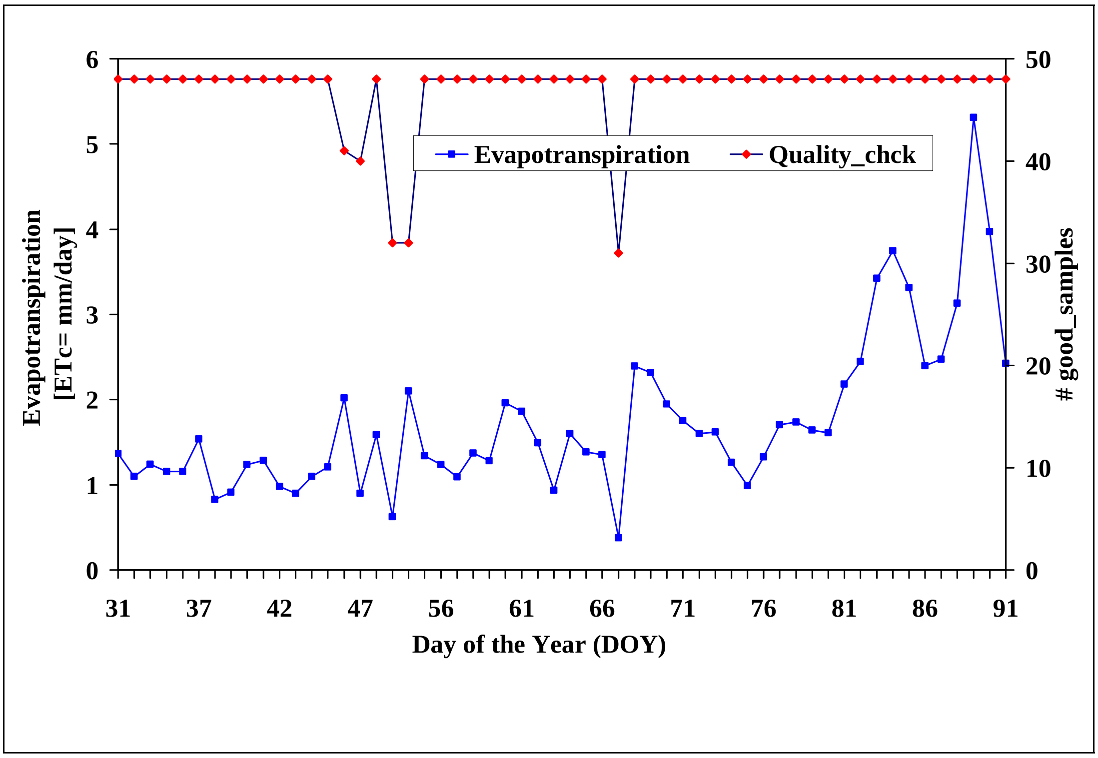


Figure 4: Actual Evapotranspiration of tomato crop during the initial period during February and March (mm/day), and number of good measurement samples.

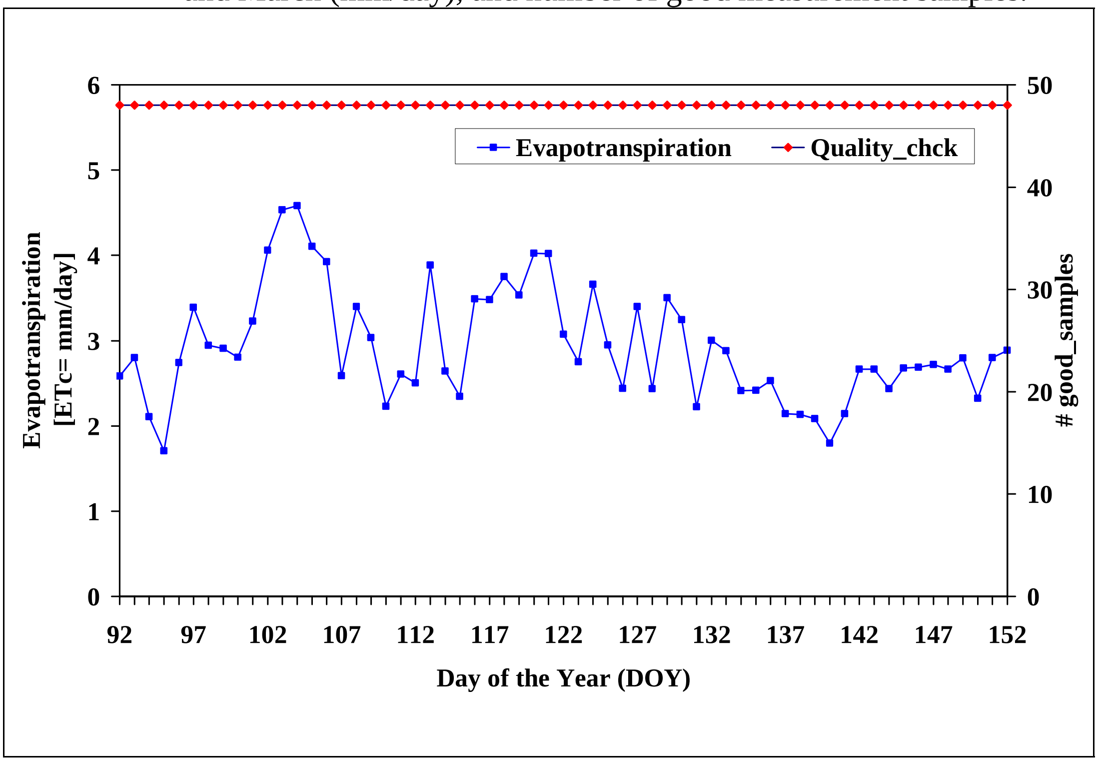


Figure 5: Actual Evapotranspiration of tomato crop within the mid stage period during April and May (mm/day), and number of good measurement samples.

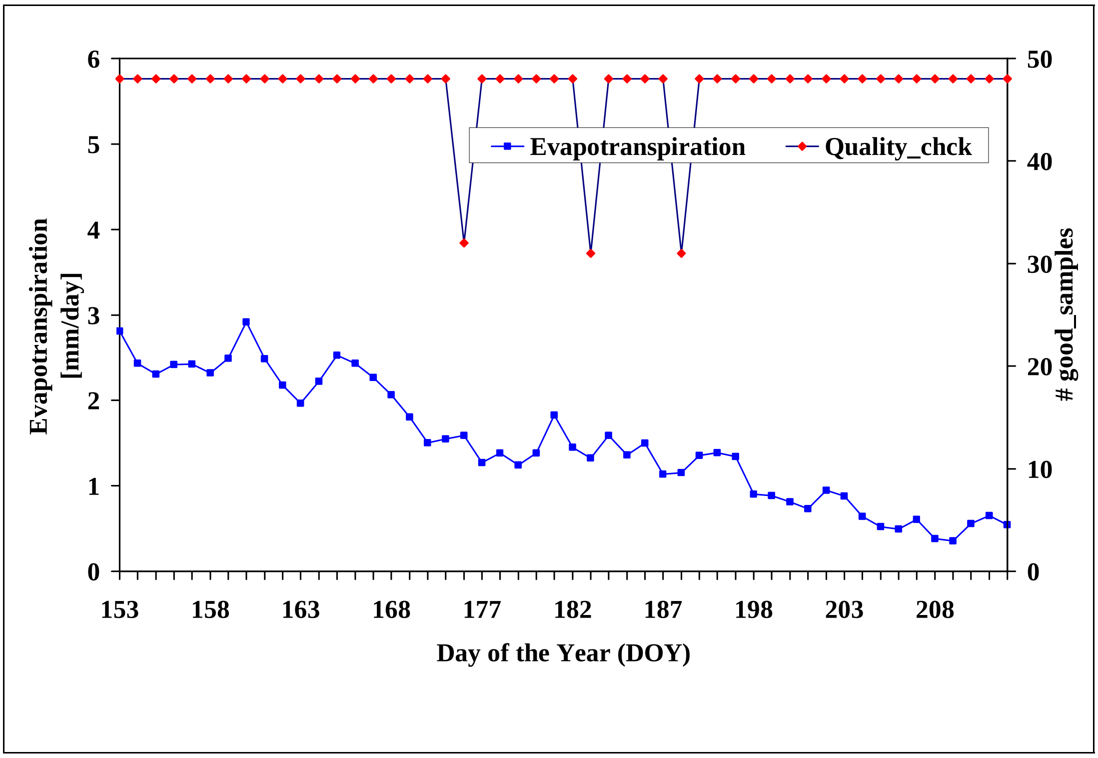


Figure 6: Actual Evapotranspiration of tomato crop at the late stage, and harvesting period during June and July (mm/day).

Results of ET_O and ET_C (Figure 7) were used to calculate K_C values for tomato crop for the whole period according to the following equation:

$$K_C = \frac{ET_C}{ET_O}$$

As Shown in Figure 8, the FAO-K_C for tomatoes were adjusted to fit the local conditions in the Jordan Valley for tomato crop planted in January, the following changes were made:

1- The K_C Value for the initial stage is increased from 0.4 to 0.65. The initial stage duration was reduced to 20 days instead of 30 days. This is due to the fact that this period was shorter than expected, and the crop had gained vegetative growth rapidly, and ET_C accumulated higher values.

2- The K_C value for the mid stages decreased from 1.20 to 0.95. The duration of this stage was adjusted to 30 days for the development stage, and 60 days for mid stage. These changes were justified by the field observations, where the plant was healthy, and ET_C values were high during this period.

3- The K_C value for final stage decreased to 0.60. This is based on farmers practice, where they tend to minimize irrigation and cultivation practices since no profitable yield is gained during this period.

Those changes are shown in Table 2.

Table 2: Adjusted K_C values for tomato crop grown in the Jordan Valley as compared to FAO-K_C values.

	Adjusted FAO-K_C for tomato crop planted in Arid Regions		**Adjusted K_C for tomato crop in the Jordan Valley**	
Crop Stage	Duration (day)	K_C-Value	Duration (day)	K_C-Value
Initial Stage (L_{ini})	30	0.40	20	0.65
Development Stage (L_{dev})	40	1.20	30	0.95
Mid Stage (L_{mid})	40	1.20	60	0.95
Late stage (L_{late})	45	(0.70-0.80)	35	0.60
Total	135		145	

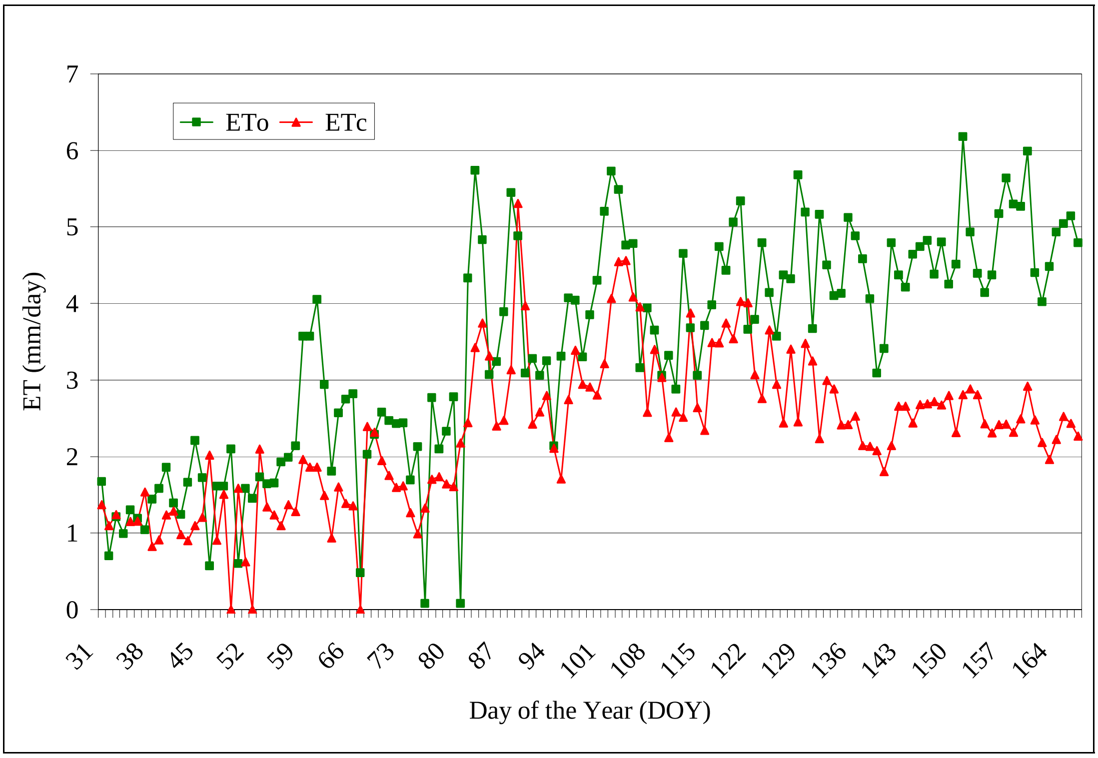


Figure 7: Actual evapotranspiration for tomato crop obtained from the EC device, and the potential evapotranspiration according to P-M equation.

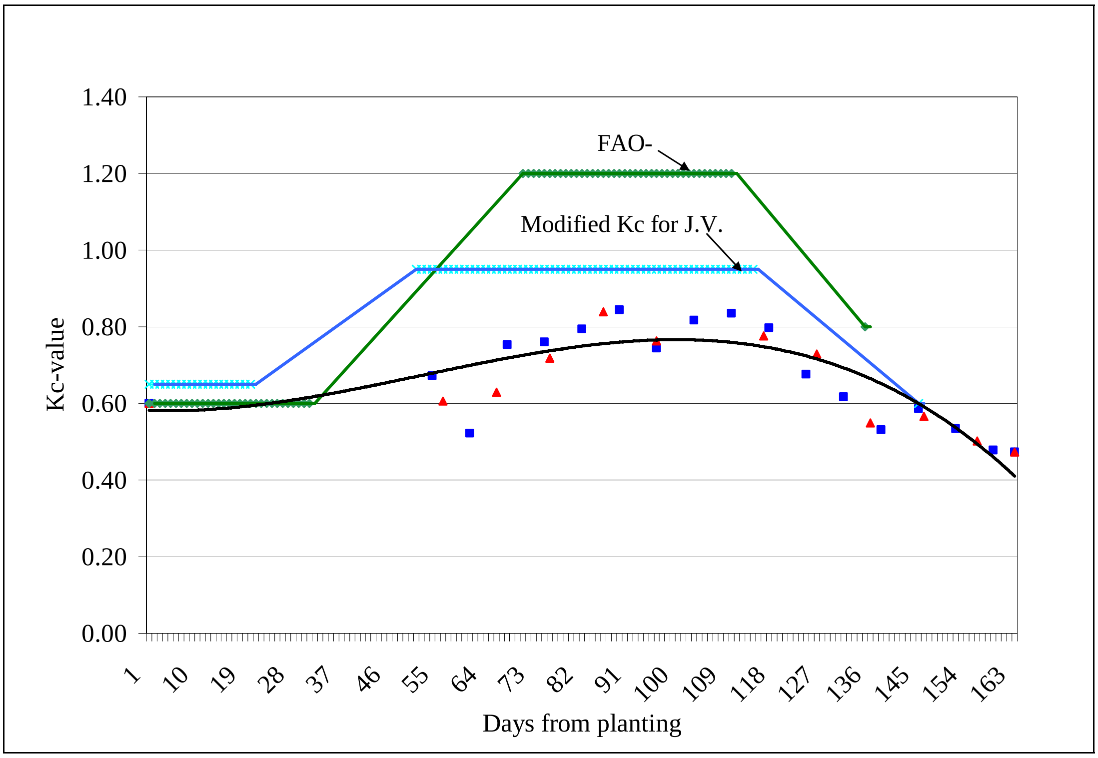


Figure 8: Modified K_C values for tomato crop grown in the Jordan Valley, and FAO values.

E.4.1.3 Sweet Corn Crop:

Actual evapotranspiration of sweet corn on daily basis were measured using the Eddy-Correlation device used previously for tomato crop. The same setup for the device were used at the initial crop stages. While at later stages (70 days after planting), when the crop reached the height of 2.0 meters, the elevation of the sonic, and net radiation sensors was raised up to 2.8m and 2.5m respectively. These changes were made after the Julian day of the year (DOY) 277, consequently this was taken in consideration in the analysis of the results and calculations. Reference crop evapotranspiration (ET_O) according to Modified Penman-Monteith equation were obtained from a nearby automatic weather station for NCARTT.
Results of sweet corn evapotranspiration ET_C and ET_O, are discussed below, and are shown in Figures 9, 10 and 11.
The total ET_C for sweet corn measured in this experiment is equal to 274mm. The amount of water to be added to the field is estimated to be 430 mm taking in consideration the leaching requirements (15%) and overall irrigation efficiency (75%). Similar to the procedure used to produce K_C values for tomato crop, K_C values for sweet corn were obtained and shown in Figure 12. The FAO-K_C values for sweet corn[3] were modified to fit the local conditions in the Jordan Valley as following:

[3] These values are applicable to Sweet Corn crop planted in August.

1- The K_C Value for the initial stage was reduced from 0.70 to 0.50 for a duration of 15 days instead of 20 days as suggested FAO, since it was noted that this period was short, and the crop canopy was small.
2- The K_C value for the mid stages decreased from 1.25 to 0.90. Changes were also made to the duration of this crop stage to be 25 days for development stage, and 35 days for mid stage (45 days after planting). In the development stage, the plant height increased rapidly, and ET_C was high during the mid stage. The crop height reached 2.50 m, and percentage cover reached 95% .
3- At the final stage the K_C value decreased to 0.85. The total plant life duration is increased 10 days more (90 days instead of 80 days). This is because the sweet corn variety (***Assgro)*** requires 90 days. Summary of these changes is shown in Table 3 below.

Table 3: Adjusted K_C values for sweet corn grown in the Jordan Valley as compared to FAO-K_C values.

	Adjusted FAO-K_C for sweet corn crop (Maize)		**Adjusted K_C for sweet corn crop in the Jordan Valley**	
Crop Stage	Duration (day)	K_C-Value	Duration (day)	K_C-Value
Initial Stage (L_{ini})	20	0.70	15	0.50
Development Stage (L_{dev})	25	1.25	25	0.90
Mid Stage (L_{mid})	25	1.25	35	0.90
Late stage (L_{late})	10	1.05	15	0.85
Total	80		90	

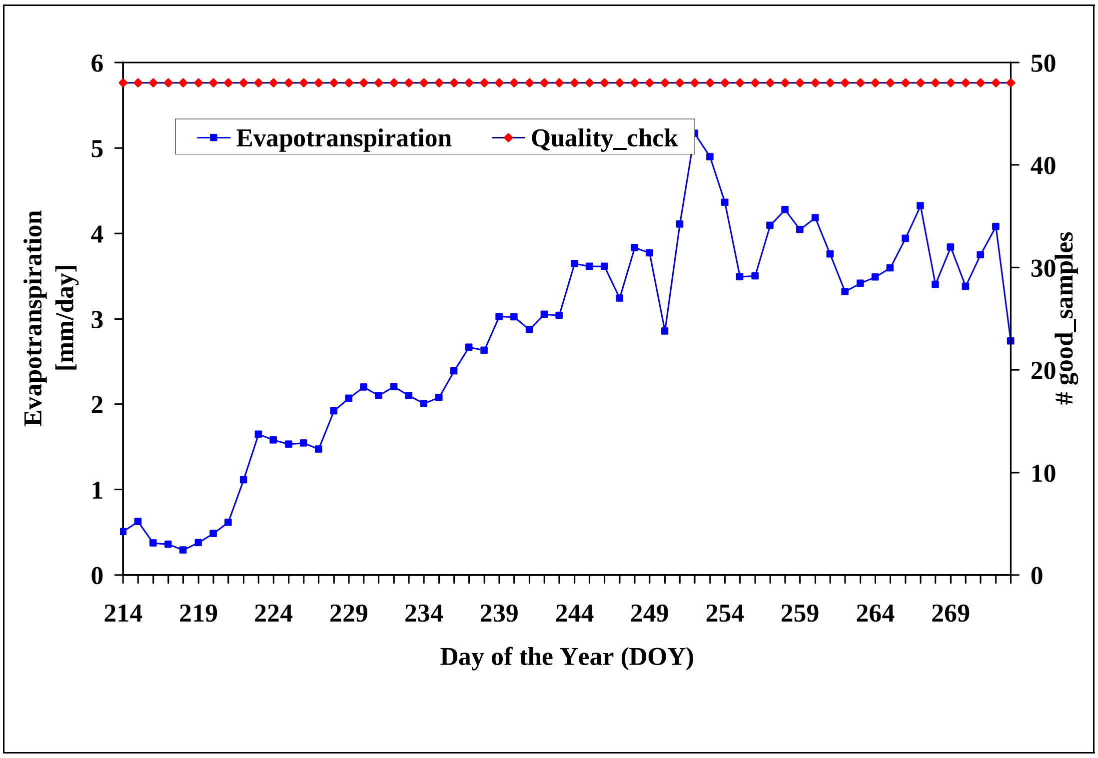


Figure 9: Actual Evapotranspiration of sweet corn during August and September.

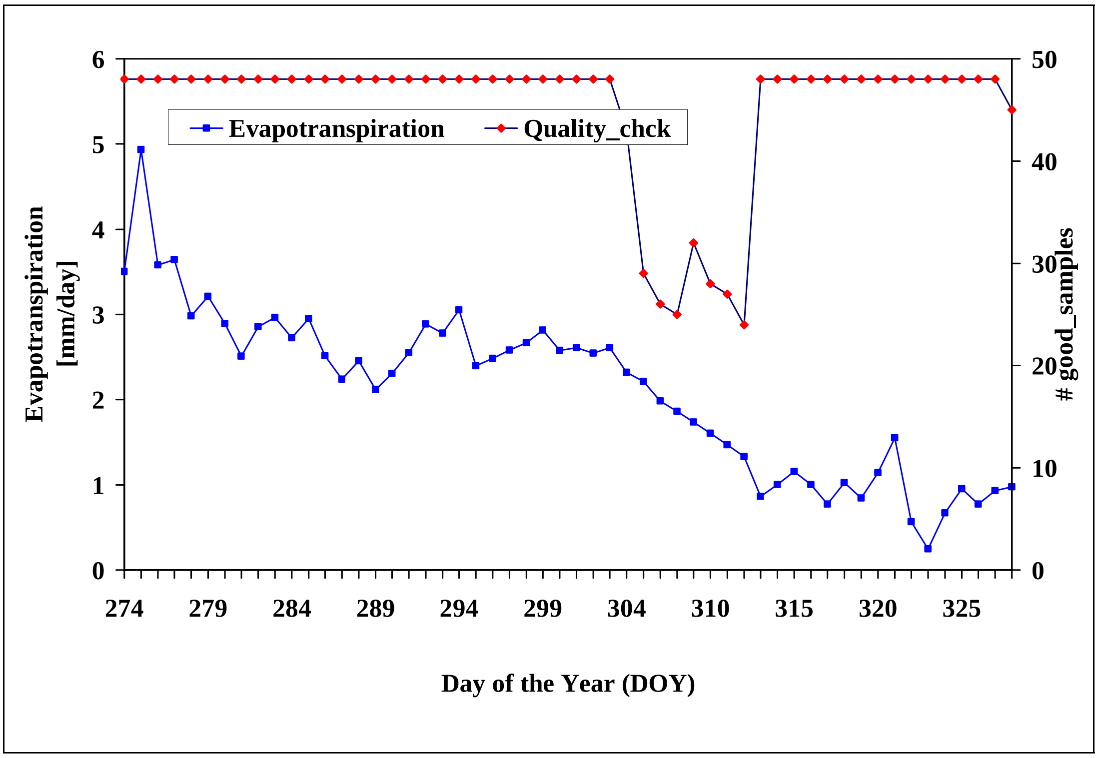


Figure 10: Actual Evapotranspiration of sweet corn at mature, and harvesting crop stages.

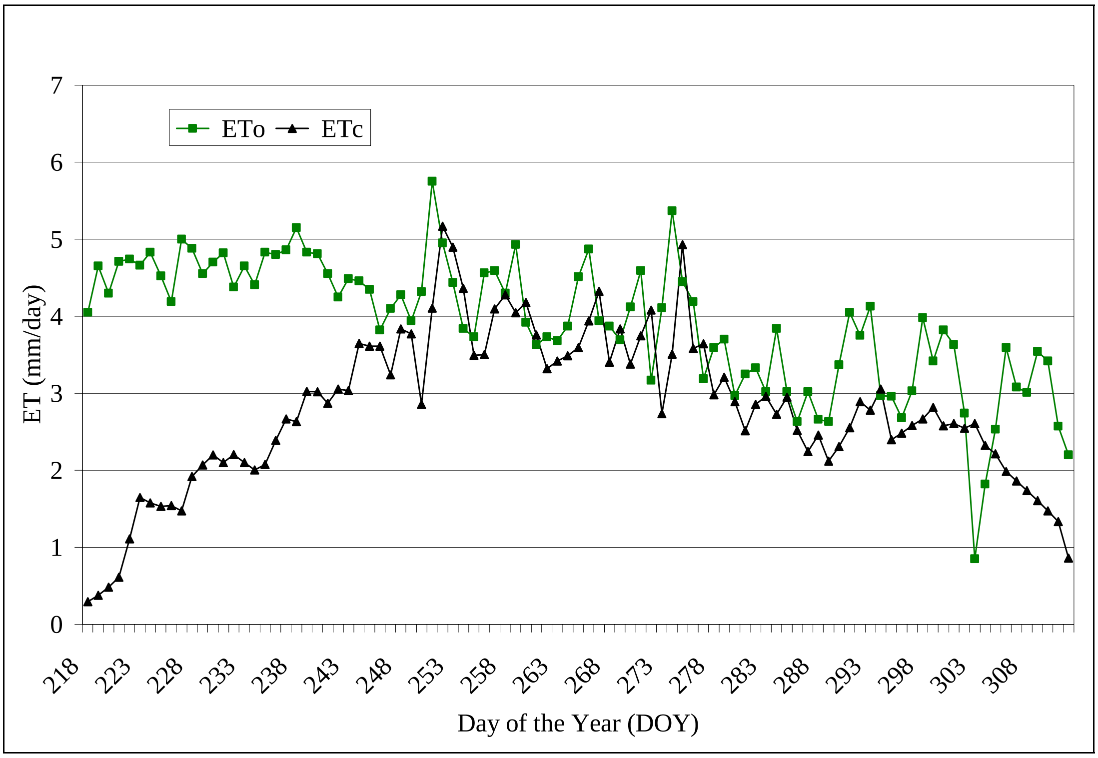


Figure 11: Actual evapotranspiration for sweet corn obtained from the EC device, and reference crop evapotranspiration according to P-M equation.

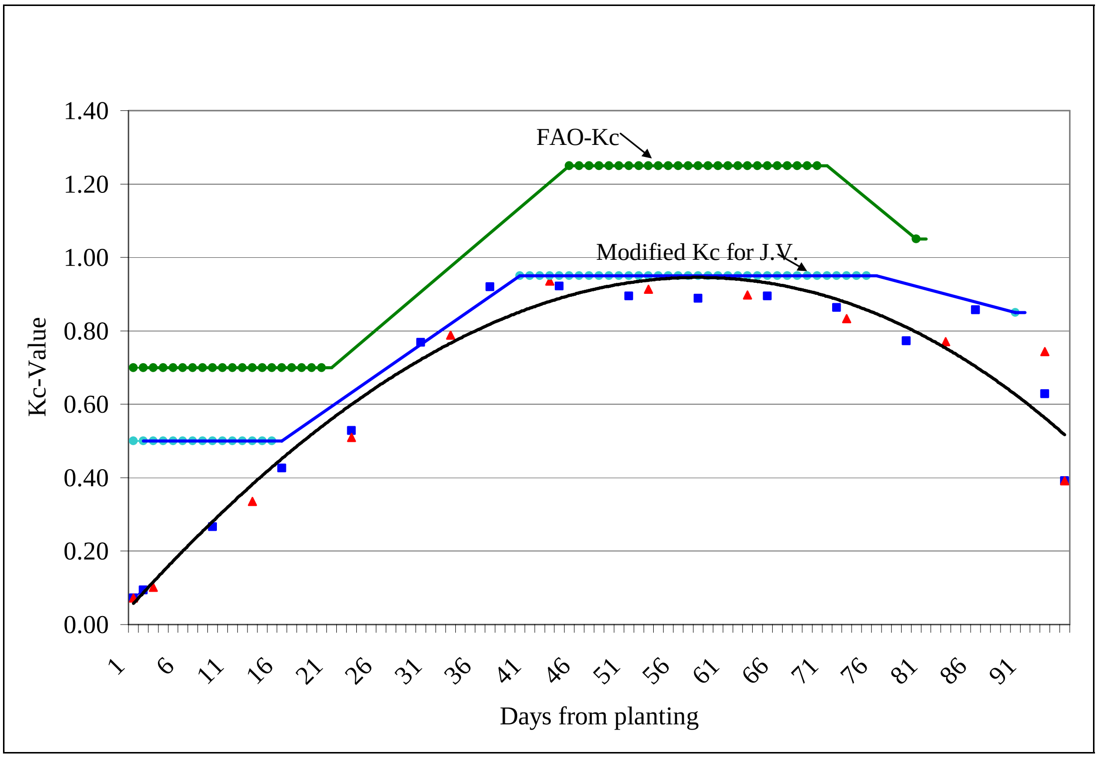


Figure 12: Modified K_C values for sweet corn crop grown in the Jordan Valley, and FAO values.

E.4.1.4 Potato crop:

The area of this field was about 2.0 ha as shown in figure 3. The field was planted with Potato crop between the periods of 14th -21st December 2004. Crop data (Irrigation, Fertigation vegetation crop width and height ..etc) were collected and reported on weekly basis.
The crop was harvested on 18th May 2005. Total ET_C for Potato measured in this experiment is equal to 252mm. The amount of crop water requirements added to the field were more than 370mm[4].
Due to the availability of irrigation water in the Jordan Valley during this winter season access amount of irrigation water had been added. The plant didn't surfer from any water shortages or stress during the whole cultivation period.
The actual evapotranspiration (ET_C) results were obtained on half hourly basis as shown in Figures 13, 14, 15 and 16. At the same time reference crop evapotranspiration (ET_O), according to Modified Penman-Monteith equation, were obtained from Dair Alla automatic weather station.

[4] $CWR=ETc/[(1-Lf) \times I_{eff}\%]= 370$ mm.

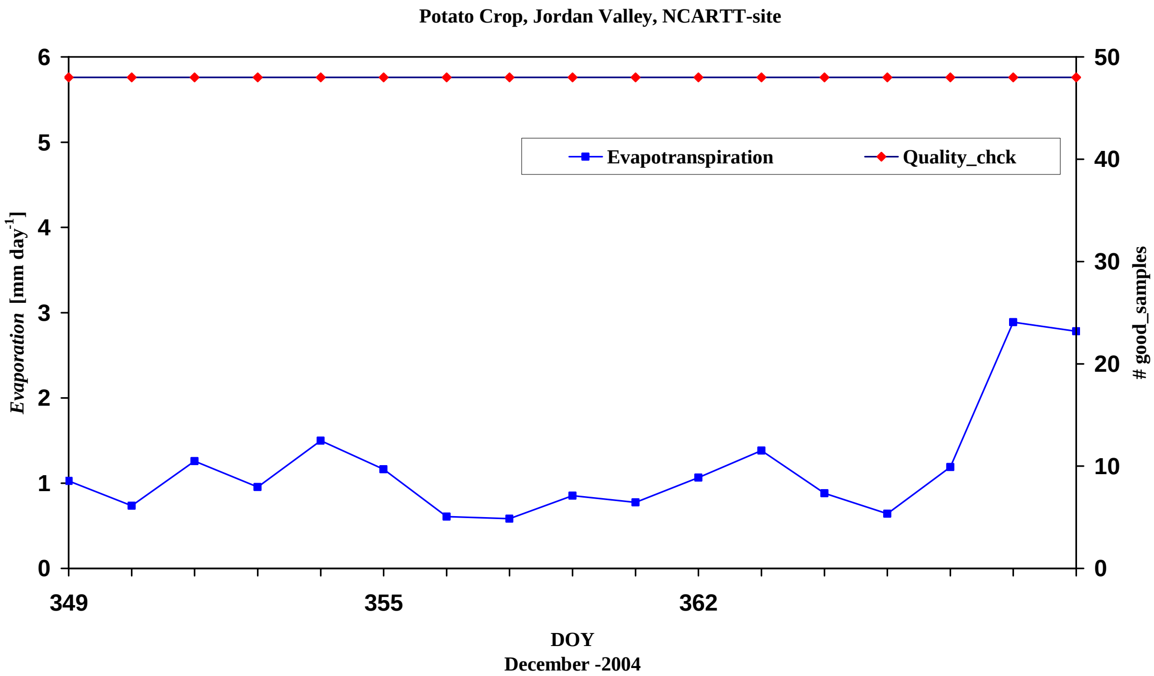


Figure 13: Actual Evapotranspiration of Potato crop during the initial period (December 2004) (mm/day), and number of good measurement samples.

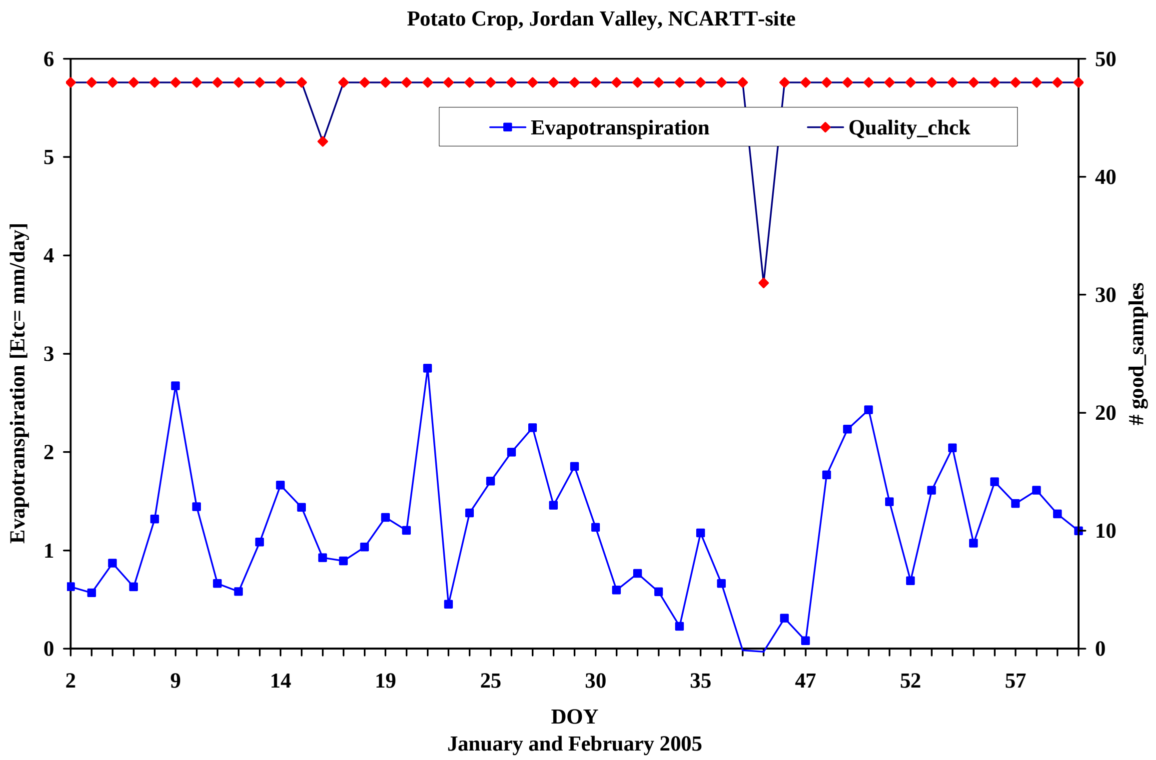


Figure 14: Actual Evapotranspiration of Potato crop during the initial period January and February 2005 (mm/day).

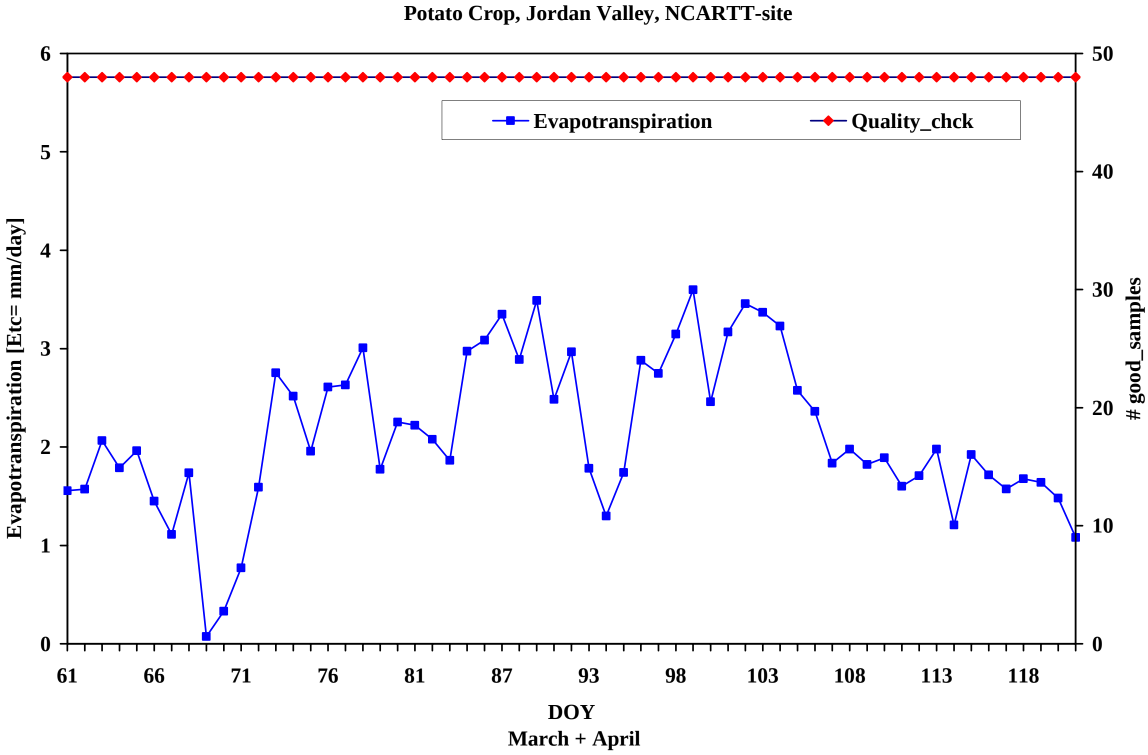


Figure 15: Actual Evapotranspiration of potato crop within the mid and late stage period during March and April 2005 (mm/day).

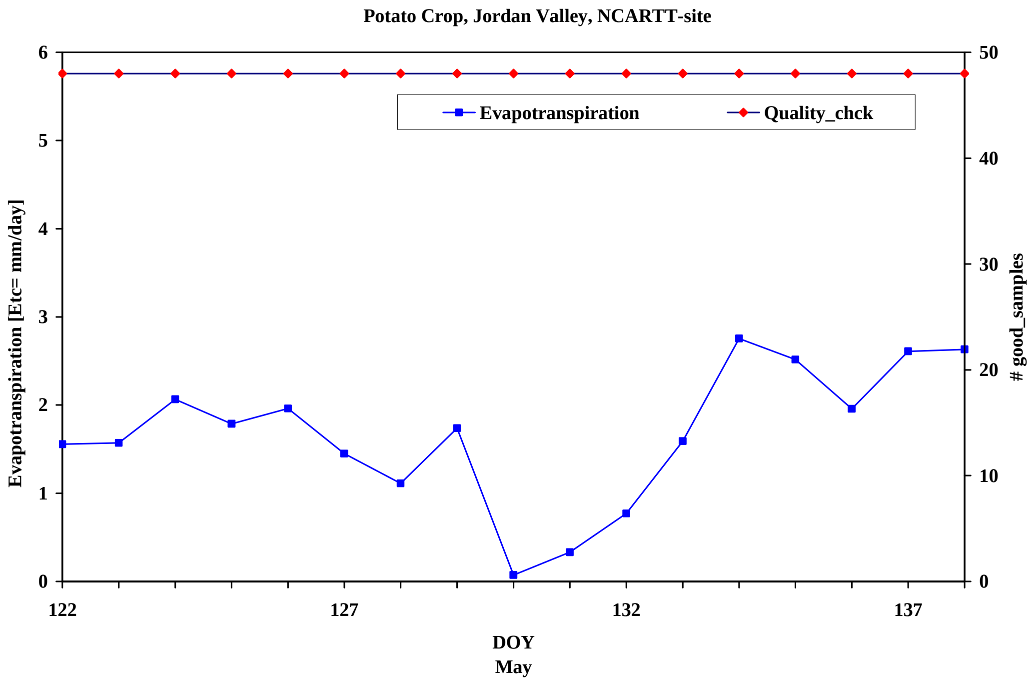


Figure 16: Actual Evapotranspiration of tomato crop at the harvesting period May 2005 (mm/day)

Results of ET_O and ET_C (Figure 17) were used to calculate K_C values for Potato crop for the whole period according to the following equation:

$$K_C = \frac{ET_C}{ET_O}$$

As Shown in Figure 18, the FAO-K_C for potato crop were adjusted to fit the local conditions in the Jordan Valley for potato planted in December, the following changes were made:

4- The K_C Value for the initial stage is increased from 0.5 to 0.65. The initial stage duration was increased up to 20 days instead of 30 days. This is due to the fact that this period was cold less than expected, and the crop did not gain vegetative growth.
5- The K_C value for the mid stages decreased from 1.15 to 1.00. The duration of this stage was adjusted to 35 days for the development stage, while it was the same as 50 days for mid stage. These changes were justified by the field observations, where the plant gained vegetation growth rapidly, and ET_C values increased relatively.
6- The K_C value for the final stage decreased to 0.50. This is similar to previous results obtained with other corps planted within this experiment. This is based on farmers practice, where they tend to minimize irrigation and cultivation practices at the end; since no profitable yield is gained during this period.

Those changes are also shown in Table 4.

Table 4: Adjusted K_C values for potato crop grown in the Jordan Valley as compared to FAO-K_C values.

	Adjusted FAO-K_C for Potato crop planted in Arid Regions		**Adjusted K_C for Potato crop in the Jordan Valley**	
Crop Stage	Duration (day)	K_C-Value	Duration (day)	K_C-Value
Initial Stage (L_{ini})	30	0.50	40	0.65
Development Stage (L_{dev})	35	1.15	20	1.00
Mid Stage (L_{mid})	50	1.15	50	1.00
Late stage (L_{late})	25	0.75	30	0.5
Total	140		140	

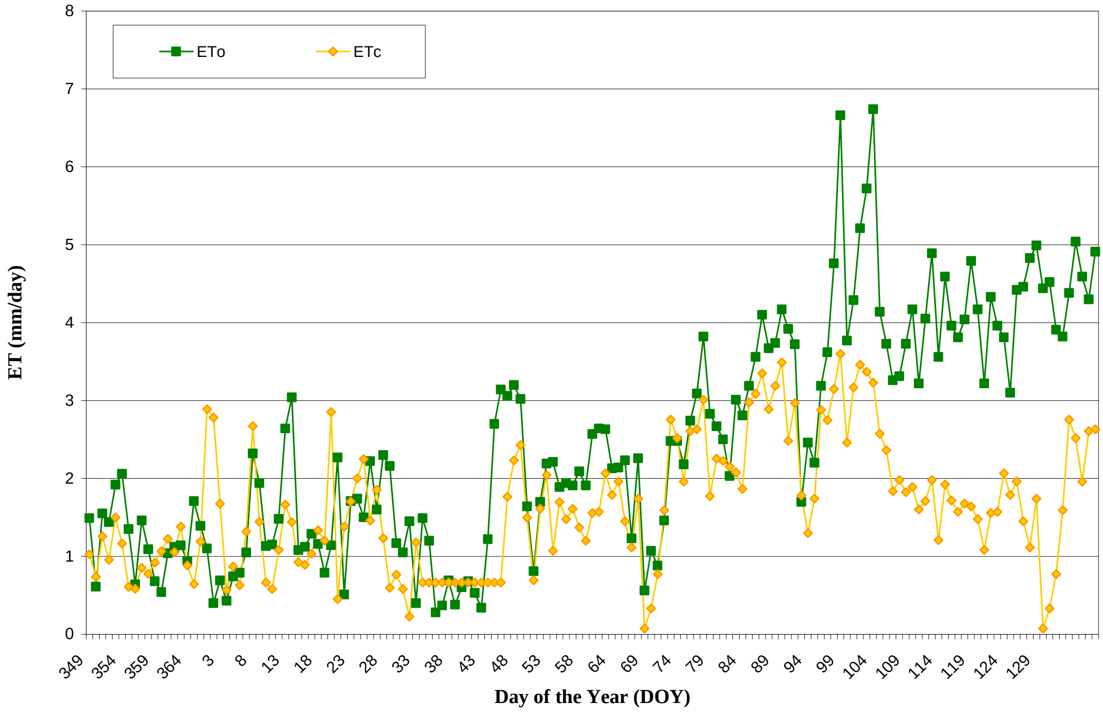


Figure 17: Actual evapotranspiration for Potato crop obtained from the EC device, and the potential evapotranspiration according to P-M equation.

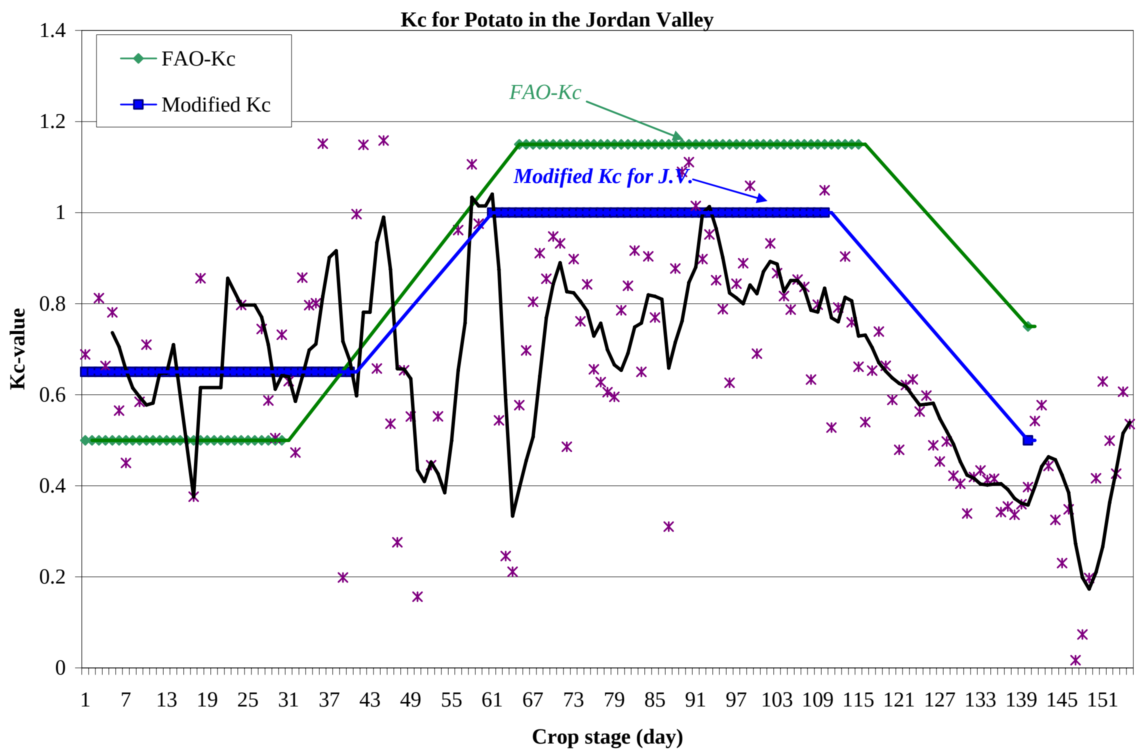


Figure 18: Modified K_C values for Potato crop grown in the Jordan Valley, and FAO values.

E.4.1.5 Cauliflower crop:

The same field was planted with Cauliflower crop at the beginning of November (4 November 2005). Crop data (Irrigation, Fertigation vegetation crop width and height ..etc) were collected and reported on weekly basis.

The crop was harvested at the end of March (23 March 2006). Total ET_C for Cauliflower crop measured in this experiment is equal to 178mm. The amounts of crop water requirements added to the field were more than 245mm[5].

The actual evapotranspiration (ET_C) results were obtained on half hourly basis as shown in Figures 19, 20, and 21. Reference crop evapotranspiration (ET_O), according to Modified Penman-Monteith equation, were obtained from Dair Alla automatic weather station .

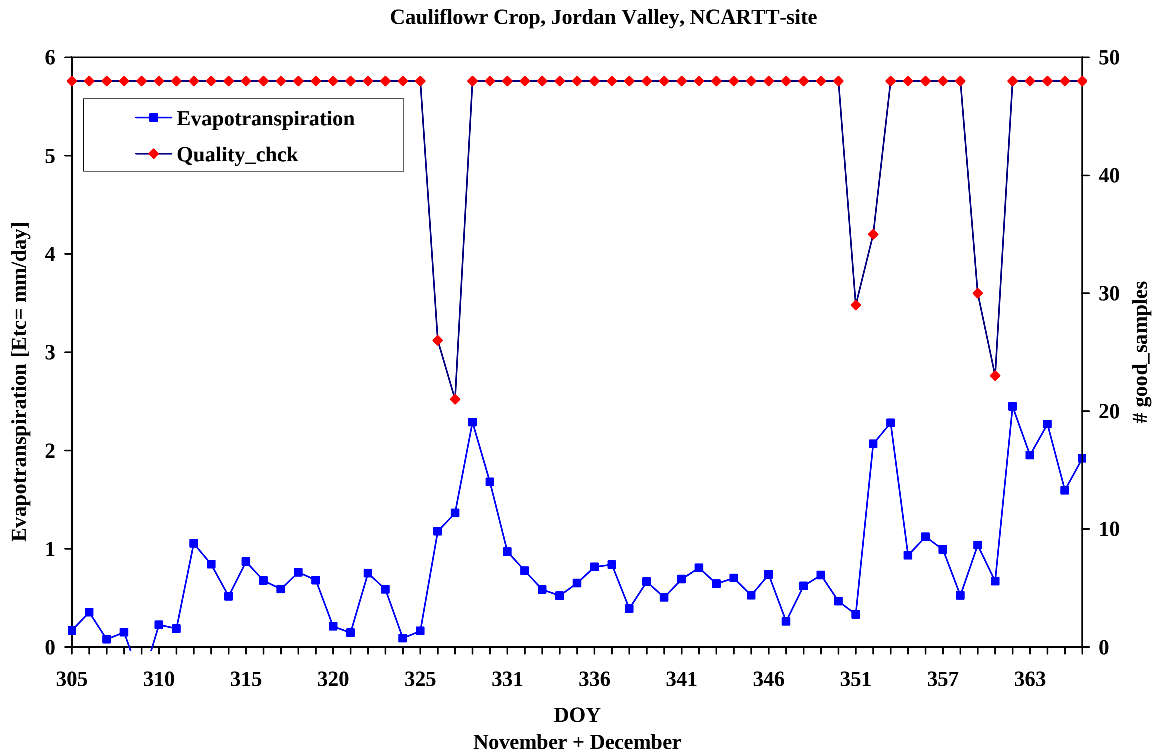


Figure 19: Actual Evapotranspiration of Cauliflower crop at the initial and mid stage November and December 2005 (mm/day)

[5] CWR=ETc/[(1-Lf) X I_{eff}%]= 245 mm.

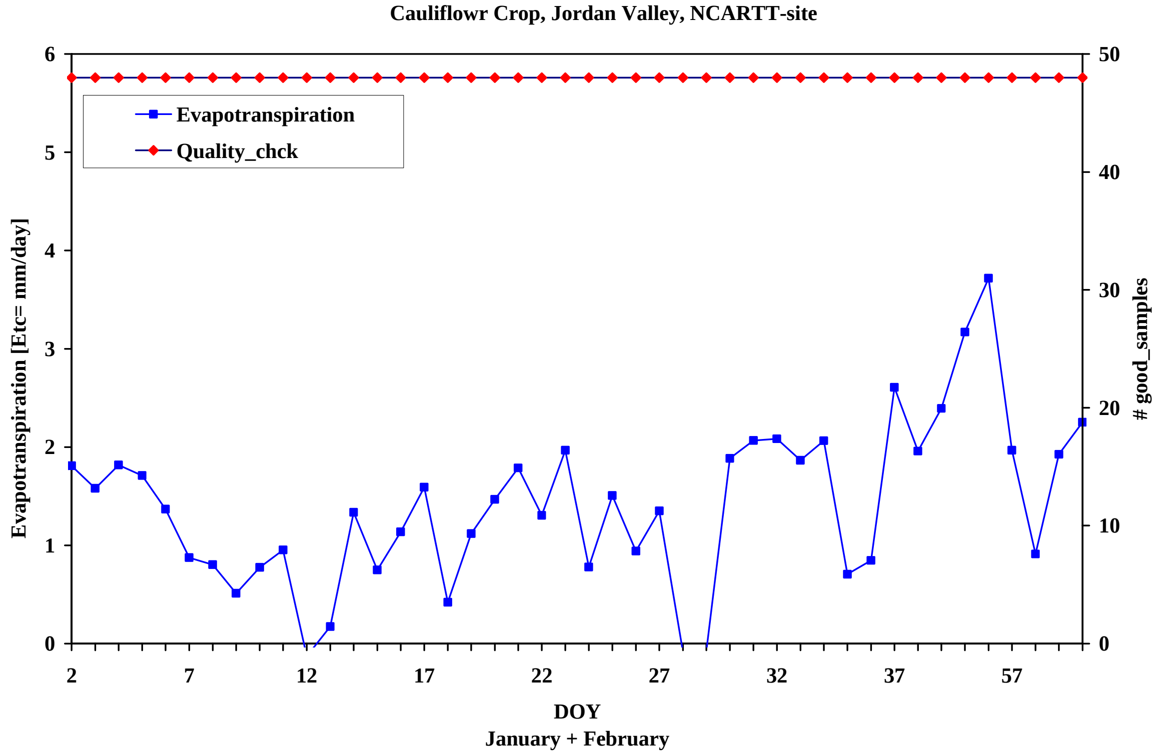


Figure 20: Actual Evapotranspiration of Cauliflower crop development and mid stage January and February 2006 (mm/day)

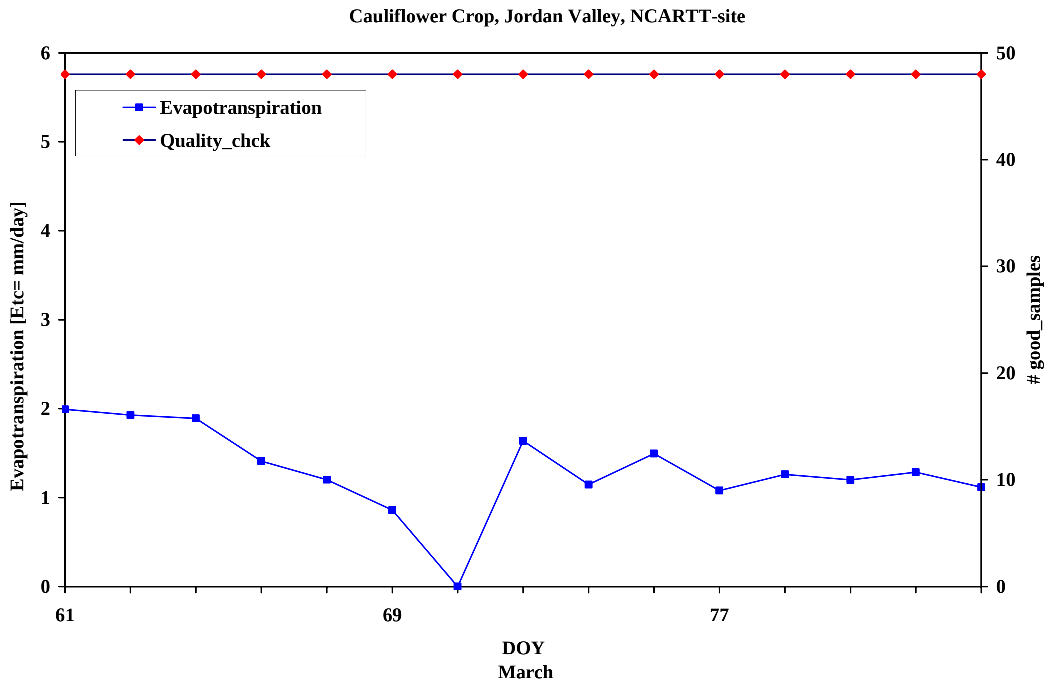


Figure 21: Actual Evapotranspiration of Cauliflower crop at the harvesting March 2006 (mm/day)

Results of ET_O and ET_C (Figure 22) were used to calculate K_C values for Cauliflower crop for the whole period according to the following equation:

$$K_C = \frac{ET_C}{ET_O}$$

As Shown in Figure 23, the FAO-K_C for Cauliflower crop were adjusted to fit the local conditions in the Jordan Valley for potato planted in December, the following changes were made:

7- The K_C Value for the initial stage is reduced from 0.7 to 0.4. The initial stage duration did not change.
8- The K_C value for the mid stages increased from 1.05 to 1.10. The duration of this stage was adjusted to 50 days for the development stage, while it was increased to 60 days for mid stage.
9- The K_C value for the final stage decreased to 0.80. This is similar to previous results obtained with other corps planted within this experiment. This is based on farmers practice, where they tend to minimize irrigation and cultivation practices at the end; since no profitable yield is gained during this period.

Those changes are also shown in Table 5.

Table 5: Adjusted K_C values for Cauliflower crop grown in the Jordan Valley as compared to FAO-K_C values.

	Adjusted FAO-K_C for Cauliflower crop planted in Arid Regions		**Adjusted K_C for Cauliflower crop in the Jordan Valley**	
Crop Stage	Duration (day)	K_C-Value	Duration (day)	K_C-Value
Initial Stage (L_{ini})	35	0.70	35	0.40
Development Stage (L_{dev})	50	1.05	35	1.10
Mid Stage (L_{mid})	40	1.05	50	1.10
Late stage (L_{late})	15	0.95	20	0.8
Total	140		140	

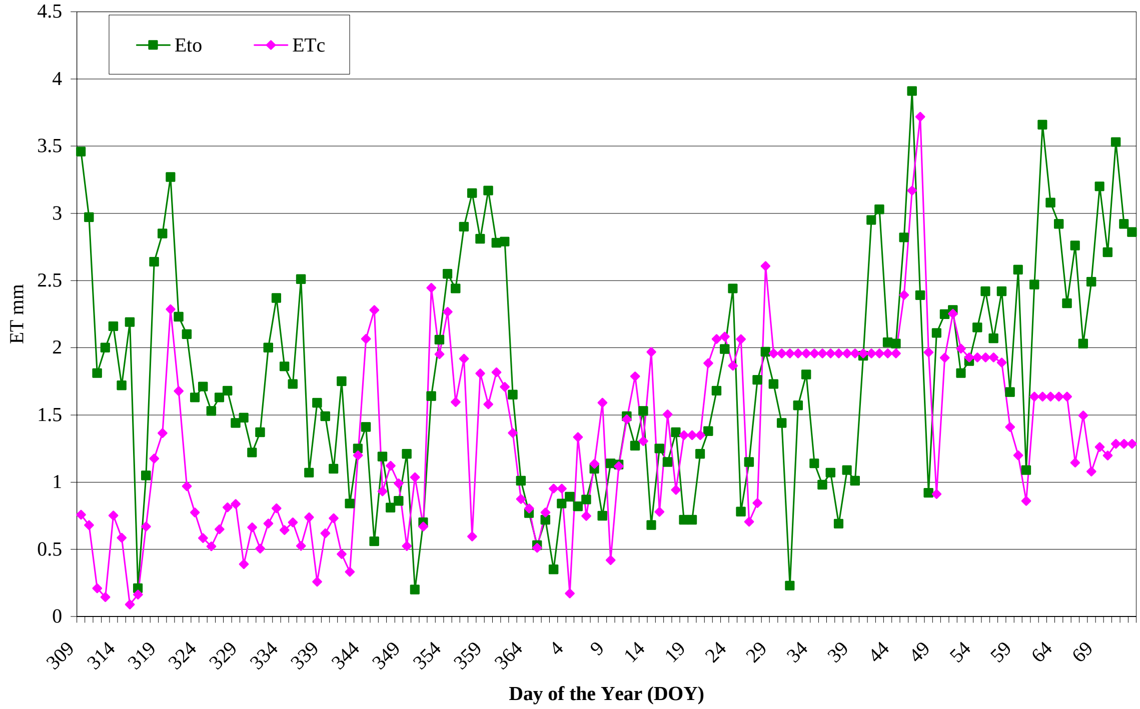


Figure 22: Actual evapotranspiration for Cauliflower crop obtained from the EC device, and the potential evapotranspiration according to P-M equation.

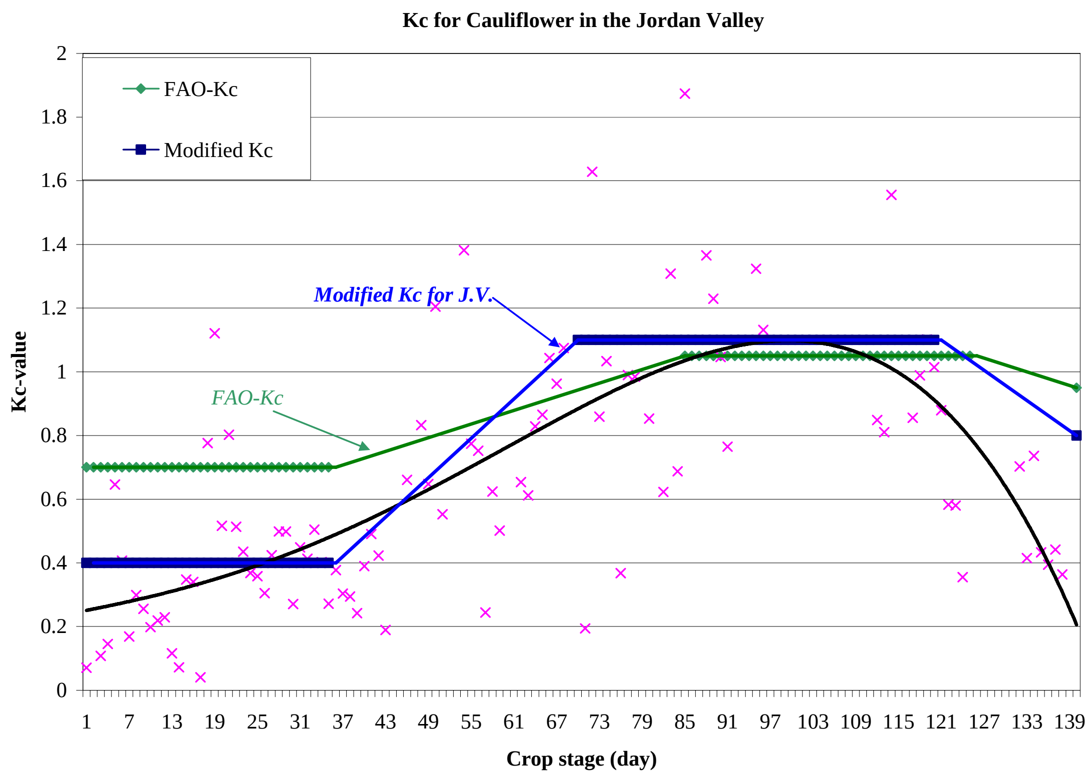


Figure 23: Modified K_C values for Cauliflower crop grown in the Jordan Valley, and FAO values.

Any other project related activities, local meetings, networking, dissemination, publications.

i. Jitan, M. A. (2005). Evapotranspiration of Major Crops in the Jordan Valley Using Remote Sensing Techniques Compared with Estimated Field Measurement Using Eddy-Correlation. Ph.D. Thesis, University of Jordan, Amman, Jordan.

ii. M.A. Jitan, 2005. Remote Sensing as a tool for irrigation management in the Jordan valley. Researcher letter No. 17, published in Arabic at NCARTT web site (www.ncartt.gov.jo) in Arabic language.

iii. M.A. Jitan, 2006. Evapotranspiration of Major Crops in the Jordan Valley Using Remote Sensing Techniques Compared with Estimated Field Measurement Using Eddy-Correlation. Agriculture Engineer Association Magazine, Amman, Jordan. Issue no. 80. Page 10, (Arabic Abstract).

E.4.2 Pertinent References:

- Allen R.G. (2000). Using **the FAO-56 dual crop coefficient method over an irrigated region as part of an evapotranspiration inter comparison study.** Journal of Hydrology, 229. pp 27-41. **(www.elsevier.com/locate/jhydrol).**

- Allen R.G., W. Bastiaanssen and B. Kramber (2001). **Remote Sensing of Evapotranspiration: Surface Energy Balance Algorithm for Land (SEBAL). (*www.idwr.state.id.us*).**

- Allen, R.G., M.E. Jensen, J.L. Wright and R.D. Burman (1989). **Operation estimates of reference evapotranspiration**. Agronomy J. 81(4): 650-662.

- Allen R.G., M. Smith and A. Pereira (1994). **An update for the definition and calculation of reference evapotranspiration.** ICID Bulletin 43(2):34-92.

- Allen R.G., L.S. Pereira, D. Raes and M. Smith (1998). **Crop evapotranspiration. Guidelines for computing crop water requirements. *FAO* Irrigation and Drainage Paper 56**. Food and Agriculture Organization of United Nations, Rome.

- Burman, R.D, J.L., Wright, P.R. Nixon and R.W Hill (1980). **Irrigation management and water requirements and water balance**. pp. 141-153. ASAE Publ. 6-81., M. Soc. Agric. Eng., St. Joseph, MI.

- Campbell, G.S. (1977). **An introduction to Environmental Biophysics**. Springer-Verlag. New York. Pp 159.

- Campbell, G.S. and M.H. Unsworth (1979). **An inexpensive sonic anemometer for eddy correlation:** Journal of Applied Meteorology, v. 18, no. 8, p. 1072–1077.

- Choudhury, B.J., N. U. Ahmed, S. B. Idso, R.J. Reginato and C.S. Daughtry (1994). **Relations between evaporation coefficients and vegetation indices studied by model simulations**. Remote Sens. Environ. 50: 1-17.

- Claudio, O. S. and J. Kjelgaard (1996). **Parameterizing Penman-Monteith surface resistance for estimating daily crop ET**. ASAE International Conf. On Evapotranspiration and Irrigation Scheduling. Nov. 3-6, 1996, San Antonio, Texas, pp 697-703.

- De Bruin, H.A.R. (1983). **A model for the Priestley-Taylor parameter**. Journal of Climate and Applied Meteorology 22: 572-578.

- De Bruin, H.A.R. (1987). From Penman to Makkink. In: J.C Hooghart (Ed.), **Evaporation and weather**. Proceedings and Information No. 39, TNO Committee on Hydrological Research, The Hague, pp. 5-31.

- Department of Statistics (DOS). (2000). **Yearly Report**. Amman, Jordan.

- Doorenbos, J. and W. O. Pruitt (1975). **Guidelines for predicting crop water requirements, Irrigation and Drainage Paper 24**. Food and Agriculture Organization of the United Nations, Rome, 179 p.

- Doorenbos, J. and W. O. Pruitt (1988). **Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24**. Food and Agriculture Organization of United Nations, Rome. 118 pp.

- Fardous, A. A. (1983). **Determination of crop coefficients for some direct and indirect methods of estimating evapotranspiration in Jordan Valley.** M. Sc. Thesis, University of Jordan, Amman-Jordan.

- Ghawi, I. O. and M. R. Shatanawi. (1986). **Water Consumption of Broad Beans and Beans in the Central Jordan Valley**. Damascus University Journal, 10: 11-23.

- Hargreaves, G. H. and Z.A. Samani (1982). **Estimating potential Evapotranspiration**. Jour. Irr. And Drain. Division , ASAE, No. IR3, Sept. Proc. Amer. Soc. Civil Eng. 108: 225-230 World water for agriculture, contract.

- Jensen, M. E., R. D. Burman, and R. G. Allen (1990). **Evapotranspiration and Irrigation Water Requirements.** ASCE Manuals and Reports on Engineering Practices No. 70., Am. Soc. Civil Eng., New York, NY, 360 p.

- Makkink, G. F. (1957). **Testing the Penman formula by means of lysimeters**. J. Inst. Water Eng. 11 (3): 277-288.

- Mazahreh, N. Th. (1993). **Determination of actual water consumption and crop coefficient of mature banana in central Jordan Valley**. M.Sc. Thesis, University of Jordan, Amman, Jordan.

- Mazahreh, N. Th. (2001). **Evapotranspiration measurement and modeling for Bermuda Grass, Alfalfa, Cucumber, and Tomato grown under protected cultivation in the central Jordan valley**. Ph.D. Thesis, University of Jordan, Amman, Jordan.

- McBean, G.A. (1972). **Instrument requirements for eddy correlation measurements**. Journal of Applied Meteorology, v. 11, no. 7, p. 1078–1084.

- Ministry of Agriculture (MOA). (1993). **The soils of Jordan. National Soil Map and Land Use Project**. Hunting Technical Services Ltd. And European Commission. Level One.

- Monteith, J. L. (1973). **Principles of Environmental Physics**. Edward Arnold London.

- **National Water Master Plan *(NWMP).*** (2004). Ministry of Water and Irrigation, Amman, Jordan. Digital Summary Version published on July, 2004.

- Neale, C. M. U., W. C. Bausch, and D. F. Heermann (1989). **Development of reflectance-based crop coefficients for corn**. Transactions of the ASAE 32(6): 1891-1899.

- Shatanawi, M. R. (1986). **Efficiency of the Jordan Valley irrigation system.** Dirasat. Vol XIII, No. 5, p 121-142.

- Shatanawi, M. R., I. Ghawi, and R. Sharaiha (1986). **Actual consumptive use of wheat and barely in the Jordan Valley**. DIRASAT, 14(2): 49-67.

- Shatanawi M. R., I. Ghawi, and R. Sharaiha (1986). **Consumptive use of Okra in the Jordan Valley**. DIRASAT, XIII: 19-25.

- Shatanawi, M. R., I. Ghawi, M. Fayyad, M. Habbab, A. Taimeh, A. Abu Awwad, J. Wolf, J. Gleason, S. Salti, M. Ababneh, M. Jitan, and M. Hamdan (1994). **Irrigation management and water quality in the central Jordan valley. A baseline report prepared for the USAID mission to Jordan**. Prepared by the water and environment research and study center, University of Jordan. Amman - Jordan.

- Shatanawi, M. Y. Al-Zu'bi, and O. Al-Jayoussi (2003). **Irrigation Management Dynamics in the Jordan Valley under Drought Conditions**. Tools for Drought Mitigation in Mediterranean Regions, 243-258. Kluwer Academic Publishers, Netherlands.

- Tanner, B.D. (1988). **Use requirements for Bowen ratio and eddy correlation determination of evapotranspiration.** Conference of the Irrigation and Drainage Division, Lincoln, Neb., July 19–21, 1988, Proceedings: New York, American Society of Civil Engineers, 12 p.

- Tanner, C.B. (1960). **Energy balance approach to evapotranspiration from crops.** Soil Science Society of America, Proceedings, v. 24, no. 1, p. 1–9.

- Taylor, S. A. and G. L. Ashcroft (1972). **Physical Edaphology**. W.H. Freeman and Company. San Francisco. pp533.

E.5 Report of partner 5 (MWI, Jordan)

Prepared by: Suzan TAHA

Background

Within the INCO-MED Program, the Ministry of Water and Irrigation (MWI) signed an agreement with the European Commission as one partner in a consortium consisting of 9 Euro Mediterranean institutions to implement the IRRIMED Project.

The project, which was launched in April 2003, aims at the following:

1. Accurate assessment of actual ETR over selected crop during the growing season, allowing to validate models and to update the crop calendar and crop water requirements
2. Remote sensing of crop extension and evolution during the growing season, to measure the actual acreages of the different crops
3. Refining existing methods for simple ETR estimation, to apply them spatially, deriving ETR maps from satellite data

MWI served both as leader for the end users work package (Work Package 6), and an end user who has stakes in improvement of the quality of data related to planning for irrigation, and update its information system with validated methods for the estimation of crops water requirements, crop factors, crops calendars and reliable estimates of crops irrigated areas. MWI also served as a local coordinator with its sister organization the Jordan Valley Authority which is responsible for the socio economic development in the Jordan Rift Valley, including the development of water resources, and management and distribution of irrigation water.

As a leader of the end users work package, MWI role was to assist MPC countries; Jordan, Syria, Morocco and Tunis adapt the projects results to suit the end users needs in the respective countries with due consideration to their local conditions.

The **following lists the deliverables related to the end users work package, as identified** in the Project technical annex,:

- Definition of the main types of end users to be targeted when discussing operational tool requirements
- Internal report to the scientific team on preliminary specifications for the development of the operational tools given Mediterranean Partner Countries specific needs.
- End users requirements
- Implementation plan

This report is divided in 2 parts; Part I: outlining the contribution of the Ministry of Water and Irrigation (Partner 5) to the various work packages and Part II presenting the consolidated scientific report following EC recommendations.

E.5.1 Part I - Contributions of Partner 6 to the other Work Packages

Contribution to Work Package 1:

The following information were provided to the UOJ (Partner 3):

1. Map of the study Area
2. Monthly Climatic Data for three stations in the study area (Baqura, Deir Alla, Wadi Rayyan) covering the period 1983 to 2002.
3. A map showing the Agro-climatic Zones of the Jordan Valley according to the classification used in MWI (Northern and Southern Jordan Valley).
4. Maps showing rainfall and evaporation stations in the study area.
5. Detailed geology maps for all the formations in the IRRIMED study area (Rijam, Alluvium, Muwaqqar, Amman/Wadi Sir, Lower Ajlun, Kurnub, Zarqa Group).
6. Soil Maps, Scale 1:250,000
7. Topographic maps for the IRRIMED study area (Contour lines at 100m intervals)
8. Land use: villages, road network, king Abdullah Canal, general land use map (4 classes: forest, orchard, brush, and built-up areas), wadis and rivers and water bodies.
9. Administrative boundary; districts and sub-districts
10. Detailed maps for the IRRIMED study areas showing the extent of agricultural development and irrigation management districts, including:
    - Farm Units
    - Development Areas representing a group of Farm Units irrigated from the same turnout.
    - Stage offices, representing the development areas, which belong to the same irrigation management unit.
    - JVA[6] Mandate area.

In order to streamline the classification schemes, obtained as a result of processing data from satellite images, with those deployed at MWI, and/or JVA, Partner 3 (UOJ) was provided with the description of the Crop groups and the Main Crop Groups used in both MWI and JVA Information systems.

Moreover, and for the purpose of comparison with land cover Maps; cropping patterns for the year 2002, were also obtained (from JVA) and made available to partner 3. Depending on the location, the 2002 data were supplemented with additional cropping patterns information for the months of July and August of 2003, and for the period Sep-Dec.2002. Data obtained included monthly irrigated areas per farm unit which could be aggregated to higher irrigation management and planning levels; Development Areas and Stage Offices.

Coordination with partner 3 (UOJ) to follow up on the results of its activities and assess the usefulness of image processing using digital image classification for preparing maps of irrigated areas and evaluate the reliability of JVA irrigation areas data.

Compilation of information related to the cropping calendar for the major crops prevailing in the study area and availing it to partner 3, to assess the reliability of remote sensing in monitoring the crop development given the high cropping intensity in the Jordan Valley, known for year round cultivation where 2-5 crops per year is widely known.

[6] JVA: one of the end users in Jordan, responsible for the socioeconomic development in the Jordan Rift Valley.

Follow up on the results of linking ground measurements of crop coefficient (Kc) and remote sensing derived parameters (NDVI).

Contribution to Work package 2:

- Identification of the major crops grown in the Jordan Valley, for which ETR needs to be measured.
- Water supply for the areas and periods selected under 1.B.1 above, were provided at the level of farm and development areas, in order to compare water supply with actual water needs.

Contribution to Work package 6:

- Coordination with partner 3 (UOJ), and follow up on the results of the activities related to the Jordanian component of work package 1, namely to:
    - Assess the usefulness of image processing using digital image classification for preparing maps of irrigated areas and evaluate the reliability of JVA irrigation areas data
    - Determine the potential usefulness of satellite image to identify cropping patterns in an intensively irrigated area, such as the Jordan Valley, for both planning and operational purposes.
    - Check the potential success for linking ground measurements of crop coefficient (Kc) with remote sensing derived parameters (NDVI).
- Follow up on the research results related to WP2, including the introduction of Eddy Correlation for the first time in Jordan, and the adjustments which need to be made on the Kc factors recommended by FAO for the selected research crops7, given the local conditions in the Jordan Valley.
- Promotion of the IRRIMED project results pertaining to Jordanian test site, among local end users, for adoption in planning at MWI, and seasonal forecasting in JVA, through dedicated meetings
- Carried out End Users needs assessment among selected end users, to identify the end users issues and requirements for improved irrigation management, given the type of the end user and the prevailing irrigation management scheme.
- Organisation of two end users meetings to bring the project scientists with the end users, and help gear the scientists towards meeting the end users requirements, and raise the end users awareness about the project results.
- Prepared an implementation Plan – See Annex II of IRRIMED_Final_Report_Annexes.pdf), outlining the requirements for the sustainable utilization of the project findings by the end users in the MPC's, and hence enable implementation of its results. The plan includes required data, methodology, cost of deployment of satellite images to serve the respective needs, and recommendation on

[7] Alfalfa, sweet corn and tomatoes.

the type of images needed, the resolution, the frequency of acquisition, and training needs (**See also "Implementation Plan in the IRRIMED proceedings"**).

Contribution to Work Package 7:

- Participated in training workshops held in partner countries:
  - Training MWI representatives on estimation of actual evapotranspiration and crop-water requirements, in the workshop that was held in Palmyra-Syria.
  - Training of Jordanian end users representatives from both JVA and MWI on the use of "Satellite Images Processing for Irrigation Monitoring" which was held in Jordan.
- Organisation of workshops with end users representatives from partner countries to introduce the projects objectives and results and strengthen regional networking.
- Dedicated meetings with IRD scientists and Jordanian partners and researchers to ensure ample exchange of knowledge and understanding of the scientific component.

Contribution to work package 8

- Attending all annual project meetings to explain progress and to plan for the future.
- Disseminating information about the project objectives to end users trough dedicated meetings (in Morocco), and locally within the MWI and JVA.
- Providing information to supplement the project website and facilitate results dissemination and communication within and outside the project.
- Establishment of a link to the IRRIMED website, and its publications, on both the MWI and Jordan's EMWIS [8] National Focal Point websites.

[8] The Euro Mediterranean Information System on the Know How in the Water Sector

E.5.2 Part II - Consolidated Scientific Report

E.5.2.1 Objectives of the End Users Work Package:

The objective of this work package is as follows:

Discuss the application of the project results **in interaction with end users** and ensure appropriate coordination between the IRRIMED scientific team and the end users in the Partner Countries, in order to enable implementation of the project's results in a follow-up operational phase taking into account local technical and economic considerations.

MWI led the end users requirements Work Package - WP6 in order to:

1. Ensure that end users requirements and issues are considered by the scientists, given the varying local conditions in the MPC's

2. Introduce the relevant results of the scientific components:
   - The use of eddy correlation for the measurement of crop evapotranspiration (Etc); and demonstrate its results and its applicability for evaluating the performance of the classical FAO ETR estimation methods (based on ETo and crop coefficients Kc), under local conditions.
   - the applicability of remote sensing based approach to the end users, with respect to identification of crop types, and improved crop monitoring (crop calendar) and the spatialization of estimated Etc under local conditions

E.5.2.2 Activities

In order to ensure successful implementation of this component of the project the following activities were carried out:

E.5.2.2.1 Activity One: Definition of the end users communities and typology:

Objective

Define the main types of end-users (in private and public sectors) that will utilise the scientific outputs of the project.

Methodology

In cooperation with the IRRIMED project partners in the Mediterranean Countries, the types of end-users that could utilise the scientific outputs of the project were identified through general discussions undertaken during meetings and via emails.

Results

Public organizations involved in water resources planning and/or distribution of irrigation water in the Mediterranean Partner Countries were targeted. Being public, these organizations have dissemination capabilities that can be far reaching and can make the project expected results useful to other beneficiaries, such as farmers, water users associations, or other regional offices in the country.

The targeted end users generally had to fulfill the following criteria:

- Be a potential beneficiary of the project output, and
- Has stakes in improved information availability to better support resources allocation and irrigation management.

See also table 1 for selected end users.

E.5.2.2.2 Activity 2: Assessment of End Users Requirements

Methodology

1. Selected end-users in the MPC's were identified in cooperation with the MPC's and end users were introduced to the project and work package objectives through dedicated meetings (ORMWAH, MWI, and the Jordan Valley Authority) and dissemination of letters prepared to this effect . Selected end users are listed in table 1 below:

Table 1: Selected End Users in the MPC's

Organization	**Country**	**Organisation Type and Role**
Jordan Valley Authority - JVA	Jordan	Governmental; planning and distribution of irrigation water.
Ministry of Water & Irrigation - MWI	Jordan	Governmental; planning of water resources
General Commission for Scientific Agricultural Research - GCSAR	Syria	Governmental; Preparation of irrigation water requirements plans.
ORMVAH	Morocco	Governmental; planning and distribution of irrigation water
Assoufit	Morocco	Private farm, which exploits an agricultural land mostly of fruit trees.
Directeur au Commissariat Régionale de Développement Agricole (CRDA) Nabeul	Tunisia	Governmental; planning & distribution of irrigation water.
Direction Générale de l'Aménagement et de la Conservation des Terres Agricoles, Ministère de l'Agriculture (DGACTA)	Tunisia	Governmental; agricultural deveopment

2. A common survey questionnaire was prepared aimed at the identification of the end users issues and requirements in the three Mediterranean Partner Countries (Tunis, Morocco,

Syria and Jordan). The questionnaire, which was disseminated to the selected end users, was followed by a detailed review, compilation and analysis of the end users survey results; a summary of which was presented in the first end users meeting with the project scientists.

3. The questionnaire was organised in 2 sections (see below), in order to enable identification of the context, and the specific conditions under which each end user is operating, and the respective needs, given these conditions.

   Section I (Background Information)

   - General Information about Organisation
   - Climate & Water Resources in the mandated region of the end user.
   - Water Demands in the mandated region
   - Projects Information and Water Supply/Allocation

   Section II: Summary of End Users Issues

   - Knowledge of Crop Water requirements
   - Knowledge of Irrigated Areas.
   - Availability of Meteorological Information
   - Availability of Information Systems incl. GIS & Remote Sensing
   - Potential End users that could benefit from the results of the Project.
   - Information needed to better manage irrigation water.
   - Issues that research need to address in order to improve efficiency of irrigation

4. Organisation of a one day end users meeting which was held on December 5th 2004, in Amman, Jordan. The meeting included IRRIMED Project Scientists (IRD Toulouse and IRD Marrakech), Partners from UOJ (P3), NCARTT (P4), and MWI (P5) in addition to end users representatives from the 4 MPC; (Tunisia, Morocco, Jordan and Syria) listed in table 1 above.

5. Assessment of the end users needs and reparation of a report on the End Users Requirements, which was disseminated to the projects scientists.

Results

The end users main issues were focused around the following:

1. **Crop type identification**

- Since the allocation of water by irrigation management institution is done on the basis of the actual irrigation areas, and not on the area of farms or potential irrigated area, the knowledge of the **actual irrigation areas at various times of the year** is a basic requirement of all end users. This however is not so applicable for planning purposes at MWI, which hosts an extensive database on irrigation areas by crop group, in order to enable estimation of water requirements, and assess future demands using various scenarios including changes in cropping patterns.
- The identification of the **main species regarding irrigation** (e.g. trees and annual crops, and possibly more details) is also requested. This information about land cover is all the more important as the statistics available from farmers' declarations or ground survey are not considered reliable by the managers.

2. **Actual crop development**

- As the allocation of water is done on the basis of an equal distribution over actual irrigated areas, regardless of the types of crops irrigated (such as in the case of ORMVAH), or based on quotas assigned for main crop categories, (Ex: JVA) the knowledge of **actual crop development** is not a priority for the irrigation distribution, but more so for **seasonal forecasting (JVA**), and **planning (MWI)** in the absence of local research.
- Farmers could also benefit from such information as they need to know as accurately as possible the **water needs** to minimize the water input as they usually have to complement the institutional water provisions by personal inputs.
- One other use of accurate water requirement assessment offered by time series at the global level is the **estimation of pumping**, assuming the difference between observed needs and institutional inputs, is coming from groundwater pumping.

3. **Better estimates of Kc**

- The end users pointed the need for **better Kc** that may be used at the institution level for initial planning of water distribution, and at the farmer level for water input optimisation. This request covers in fact a more general request about **more reliable methods for water needs assessment**, as the FAO methods sometimes gives rough results.

Problems Encountered

- Difficulties in planning dedicated meetings with all the end users during the first year.
- No shows of some of the end users representatives, to the workshops.
- Administrative Difficulties involving obtaining approval to fund travel for MPC’s end users representatives.

E.5.2.2.3 Activity 3: Feedback for End Users and Implementation Plan

Methodology

1. Reviewed the end users needs (workshop, survey, others). Synthesized a simplified version of the first end users meeting and survey reports, which clarify end users needs.
2. Evaluated progress to date by scientific team to achieve users' requirements through interactive communication with scientists; sending the specific users needs (synthesis above), asking each scientist about the specific contribution to one or more of these needs.
3. Guided the preparation of the presentations that would be made for the **second end users meeting** held in the Dead Sea, Jordan on March 6th 2007, based on feedback from scientists
4. Conducted successive meetings with the scientific team prior to the workshop to guide the workshop presentations, and ensure they were simple and focused, and that adequate communication of the project concept and activities was made.
5. Organised the second end users meeting.
6. Prepared a plan, to enable implementation of the project's results in a follow-up operational phase.

Results

1. The workshop introduced, based on the scientific findings, the methodology needed to use remote sensing to answer the specific needs of the end users around the requirements identified in the first "end users meeting " and the "users needs assessment" reports, particularly with respect to:

- Requirements for identification of crop types and estimation of Irrigation areas, Land use, etc
- Requirements for crop monitoring; (crop calendars).
- Requirements for estimation of Crops water requirements (Kc, ETo, ETc,

Presentations were targeted to demonstrate:

- the identification of crop groups using time series images with case study from the Jordan Valley and an overview on the use of remote sensing for Identification of crop types
- The use of NDVI time series for crop monitoring including monitoring for stress, with a case study from Morocco and an overview on crop development monitoring.
- Local ETp measurements (on well watered crops), using Eddy Correlation;
- Estimation of ETc using remote sensing with a case study from Jordan Valley on the use of satellite images for the spatialization of ETc .

2. A report (implementation Plan), outlining the requirements for the sustainable utilization of the project findings by the end users in the MPC's, and hence enable implementation of its results. The plan includes proposed data, methodology, cost of deployment of satellite images to serve the respective needs, and recommendation on the type of images needed, the resolution, the frequency of acquisition, and training needs (**See** Annex II of IRRIMED_Final_Report_Annexes.pdf and **Implementation Plan in the IRRIMED proceedings**).

Problems Encountered

- No shows of some of the end users representatives, to the workshop.
- Difficulties in simplifying the project results

Technology Implementation Plan

Publication of the Implementation Plan (See also result 2, Section 2.3.2) through the IRRIMED Proceedings to serve as a guide for the end users, for the application of remote sensing techniques for planning and monitoring of irrigated agriculture, with due consideration to the issues that were identified through this work package.

E.5.2.3 Training and Education

- Training of MWI representatives on “estimation of actual evapotranspiration and crop-water requirements”, in the workshop that was held in Palmyra-Syria (Feb. 2004).
- Training of Jordanian end users representatives from both JVA and MWI on the use of “Satellite Images Processing for Irrigation Monitoring” which was held in Jordan (Dec 2004).
- Organisation of 2 meetings (workshops) with end users representatives from partner countries to introduce the projects objectives and results.
- Visit of Suzan TAHA to Marrakech (Oct. 2003) in order to: a) launch the work package and get introduced to the Moroccan End Users (ORMVAH), their expectations from the project, and needs and 2) Review with the IRD scientific coordinator in Marrakech and work package leaders the progress of the scientific part of the project, revisit project objectives, expected results and foreseen parameters.
- Dedicated meetings with IRD scientists and Jordanian partners and researchers to ensure ample exchange of knowledge and understanding of the scientific component and exposure to the end users perspective.

E.5.2.4 Conclusions

Identification Irrigation Areas and Estimation of Cropped Areas:

- Problems related to the complexity of the land cover in the study area (small and many species (Jordan), very similar spectral responses (Jordan & Morocco), non synchronous development cycle of crops (Morocco), intra class heterogeneity for trees (Morocco) seriously restrict the applicability of traditional crop classification methods using satellite images.
- It was shown in Jordan that only some classes and groups of classes may be correctly discriminated. Satisfactory evapotranspiration assessment however may be obtained, without passing through classes identification since crop water requirements are closely related to vegetation amount which is linked to image information (through indices like the NDVI).
- Using high resolution image time series (every 2 or 3 weeks) and based on the temporal evolution of the spectral signature of vegetation, rough crop classes can be discriminated (annuals, trees, trees on annuals understory, bare soil). The accuracy of such methods may be higher than classical methods based on single images, and is useful for Et estimates

- Visual interpretation and supervised images classification are recommended to identify cropping pattern in an intensively irrigated area:
    - Visual interpretation is delineating boundaries to enclose group of pixels where the image reflectance is homogeneous. Later these areas are classified based on prior knowledge of the existing crop type on that area.
    - Supervised classification is done by using image-processing software to classify pixels that fall within certain range of digital numbers for different bands into one class. This is followed by giving each class the name of crop based on prior knowledge.

Improved Knowledge of Crops Water Requirements

Kc:

The type fo Kc values needed to improve water budget computing depend on its use:

- **At the farm level**, It is more economical to teach the farmer how to estimate Kc based on visual observation, or possibly using hemispherical photographs or radiometers to compute vegetation fraction cover. At the regional level, a centralized system could acquire high resolution satellite images, process them and provide farmers with estimates of Kc for each of their fields.
- **At the management level**, Actual irrigation consumption during a given period may be obtained on large surface using satellite HR image time series giving for each pixel at regular dates the vegetation development and thus Kc estimates. The future consumption is something much more difficult to obtain The two ways of investigation are the modelling approach but this which requires parameters that are impossible to obtain on large surfaces. The other approach is the statistical approach, based on libraries of observed vegetation development profiles that best fit the actual development and the climate and agronomical hypothesis.
- **At the planning level**, where better estimates of average Kc profiles of well managed crops in specific areas are needed, Eddy Correlation systems or scintillometry can be used to draw actual Kc curves. Since these experiments are expensive and can't multiply at the same time, use of satellite HR image time series can be made to monitor sets of plots of each crop over a region. In this way, a sampling of vegetation development profiles would be obtained for each crop type. Based on some Eddy Correlation field experiments during the same season, it would be possible to get Kc profiles from the NDVI profiles. Among these Kc profiles, the best ones would be considered as representative of the well managed fields, that is to say of locally adjusted Kc profiles.

Crop Calendar

The knowledge of the crop calendar in any given area would be best assessed in doing extensive field observations over the whole season. A satellite HR time series acquired during the same year would allow obtaining a development profile of plots observed on the ground.

E.6 Report of partner 6 (FSS, Morocco)

Report of Partner 6 (FSSM, MOROCCO)

University of CADI AYYAD, Faculty of Sciences Semlalia-Marrakech - Morocco

Lead scientist: Ahmed Chehbouni

Scientific Staff: Khabba S., Guemouria N., Ezzahar, J., Hanich L., Er-raki, S.

The objectives achieved by partner 6 were:

- Identified the source of the water, the main factors determining the isotopic content, and the aquifer behaviour in the Tensift Catchment.
- The use of the Scintillation Technique for Monitoring Seasonal Water Needs and Consumption of crops in Marrakech region (Semi-Arid Region).
- Spatialization of the STICS crops model in the Haouz plain
- Spatialisation of the reference evapotranspiration (ET_0)

<u>Work package 1:</u> Building the information system

1- Pedological synthesis of the Tensift watershed

In this part, we have defined the different types of pedological unit and characterized the soils (description, spatial distribution) and their hydrodynamics properties. This characterization of soils will serve to elaborate scenarios according to different types of culture.
The work was articulated around two main axes:
1 - Identification and cartography of the different types of soils
2 - Hydrodynamics properties assessment

1.1- Identification and cartography of the different types of soils

Pedological map units 1:20 000 of ORMVAH irrigated perimeters and of a cartographic complement established a long of Tensift, have been simplified and reported on a topographic map 1:50 000, (10 maps). A common legend to the whole of the ORMVAHS sectors (Haouz and Tessaout), was finished as well as the assignment of units. A draft of map simplified at 1:200 000 is available. The other cartographic data that are going to be used are the geological maps at 1 :100 000 to the south and the East of Marrakech and to the 1/250 000 on the whole of the Jbilet to the north of Marrakech. The geological map 1:500 000 have been exploited in view of a regional approach.

The priority was put on the plain in ORMVAH irrigated zone, where the identification of the pedological units was achieved for the zone R3 (Figure 1).

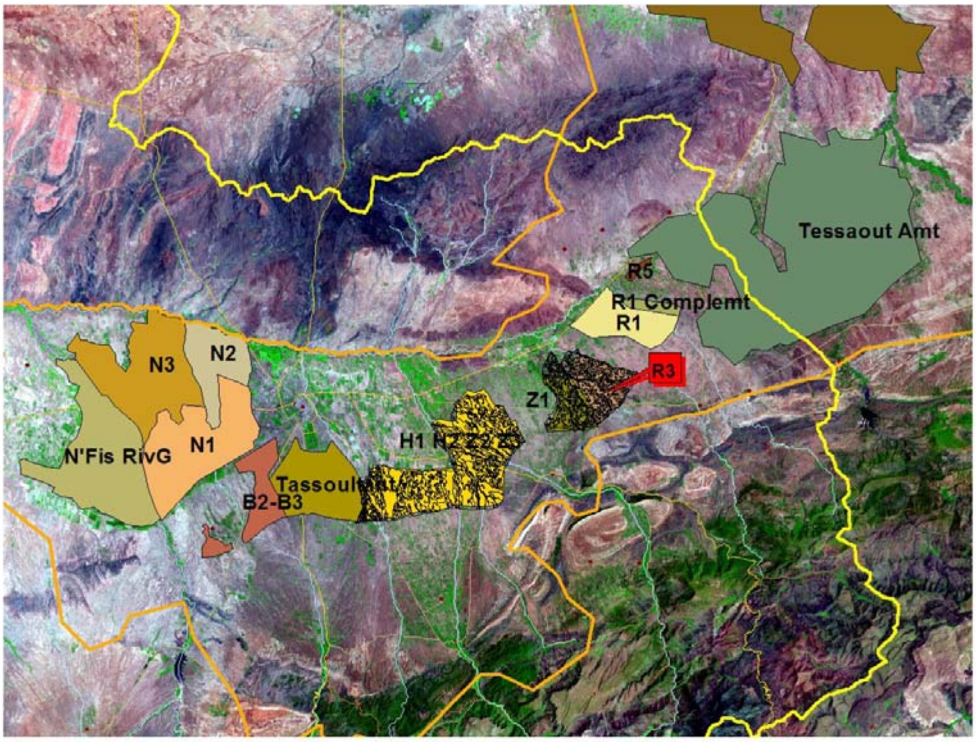


Figure 1: Main irrigated zone of Haouz plain

1.2 - Hydrodynamics properties assessment

The hydrodynamics properties of the soil of the R3 perimeter were characterized and their spatial variability was studied. A set of 32 tests of infiltration has been achieved on 5 parcels of the block 27 of this zone with the help of the Beerkan method. A first stage consisted in doing, in addition of tests of infiltration, granulometrique analysis of samples appropriated in the different parcels. This stage permited to determine properties of soil notably the hydraulic conductivity (Ks). This result watches a spatial variability of soil parameters.

2- Elementary and isotopes hydrochemistry of precipitations and relation with the underground waters in semi - arid region (case of the basin watersheds of Tensift)

The exam of the first results of analyses of the major elements, the oxygen 18 and the deuterium permits to give the following findings:
For wells the chemistry reveals two groups of water:

- Waters greatly mineralized to chemical featureses, calcic chloride - sulphate-magnesium. This mineralization can be bound to geological formations, saliferous clays of the Plioquaternaire.
- Waters calcic Bicarbonate and magnesium. These last circulate in the chalky formations and dolomites of the Cretaceous.

- The isotopic contents of underground water represent the precipitate waters from different altitudes but mixed and brazed before infiltrating at the level of the permeable zones to the piedmont of the Atlas (at an altitude of the order of 1100 meters).

3- Rainfall isotopic composition: Application for groundwater research in Tensift catchment area

The results of the analyses done during the practicum have been completed by the data of debit, of atmospheric temperature and the electric conductivity.
The first interpretations of these data indicate that the surface water like rainwater and groundwater shows a mixture between the Atlantic and Mediterranean masses.

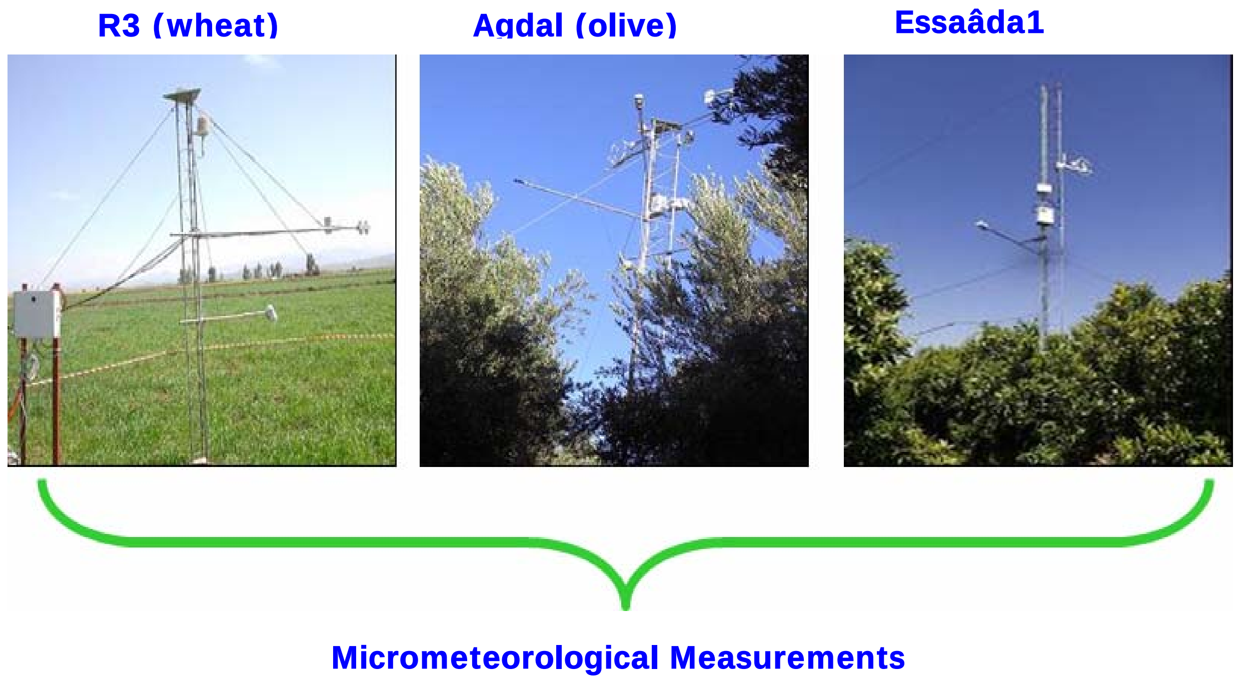
Work package 2: Field micrometeorological measurements

During the live of irrimed project, four sites which are located in the Tensift catchment area, have been instrumented with micrometeorological measurements: named "Agdal", "R3", "Sâada1" and "Sâada2".

The Agdal site is an irrigated olive yard (flood irrigation), which is located in the southeast of the city of Marrakech, Morocco (31°36'N, 07°59'W), this site was operated during two seasons (2002 & 2003). The irrigation method used is flood irrigation. The fluxes were measured with the Eddy covariance and the scintillometer. In addition the field was equipped with a set of standard meteorological instruments to measure wind speed and direction (Young Wp200), air temperature and humidity using vaisala HMP45AC probes and radiation. The soil heat flux is measured by the heat flux plate. Moisture is monitored by TDR located at different deep and the soil temperatures are measured by thermistances located at the same distance from the soil surface.

In Essaâda 1 (15 km west of city; 31°37'36''N, 08°09'35''W), the measurements were made from the end of December 2003 and it still recording until now. A large Aperture scintillometer (LAS) was installed over a path of 500m to estimate the sensible and latent heat fluxes at large scale. The measurement height is about 9m. At the same time, an Eddy Correlation (EC) system was installed above the canopy at 6.9m. The EC system consisted of a 3D sonic anemometer (CSAT3, Campbell scientific Ltd.) which measured the fluctuations in the wind velocity components and temperature, and an open-path infra-red gas analyser (Li7500, Licor, Inc.) that measured concentration of water vapour and carbon dioxide. In addition the field was equipped with a set of standard meteorological instruments as in Agdal.

Essaâda 2 (10 km west of city; 31°63'73''N, 08°13'73''W) was equipped with the same instrument expect the Large Aperture Scintillometer. The experiment was started in March 2005 and it still working until now.



Work Package 3: Model developments

3.1 STICS model

3.1.1 Validation and calibration of STICS model

The shoot growth module and grain yield of the STICS crop model were calibrated and validated by using field data which was collected from irrigated winter wheat fields in the Haouz plain near Marrakech. The calibration was performed on the thermal units between the four phenological stages that control the dynamics of leaf area index and the thermal unit between emergence and the beginning of grain filling. The plant phenology was calibrated for three fields monitored during the 2002/03 season. Evaluation of the grain yields and the temporal evolution of leaf area index were done for six validation fields during 2003/04. The results showed the significant accuracy of the model in simulating these variables, and also indicated that the plants mainly suffered from lack of nitrogen. The results show also that the potential of crop modeling to schedule irrigation water, on the assumption that the plants were growing under optimal conditions of fertilization. In this case, the model was used to manage the time of irrigation according to a threshold for water deficit. Various simulations displayed logical trends in the relationship between the grain yield and both the amount and timing of irrigation water. These results were finally compared with those obtained from real irrigation practices. For the particular climate of 2003/04, the comparison showed that 70 mm and 40 mm of water could be saved in case of early and late sowing, respectively.

3.1.2 Spatialization of the STICS crops model in the Haouz plain

We have presented a calibrating and testing of STICS crops model in the Haouz plain conditions. In the present report we present a first attempt to spatialize this model. The data used are collected in the semi arid Haouz plain area in 2002-2003 wheat seasons. Ten satellite images high space resolution (20m) were acquired between November 2002 and June 2003. A classification method allowed us to classify the studied zone (3 km x 3 km) in 50 classes of temporal profiles of Leaf Area Index (LAI). From these profiles, we retrieved the sowing date, considered as an important STICS input.

3.1.3 Sawing dates

The beginning of the emergence stage was considered when the LAI reach a threshold of $0.2 m^2/m^2$. From each temporal profile of LAI, we deduce the emergence date for each class. The sowing date was considered 20 days before the emergence stage starts, as simulated by STICS (Hadria et al., 2006a).

The spatialized LAI profiles and sowing dates were used to calculate, using STICS, the spatialized real evapotranspiration and yield. The required soil parameters were deduced from the soil map of the studied region. For the irrigation dates, the data collected by the regional agricultural office were used. The temporal evolution of LAI were used to calibrate the model, while the sowing and irrigation dates, the soil parameters and climatic data were used to describe our simulated system.

3.1.4 Real evapotranspiration

The calculated real evapotranspirations cumulated along the wheat season (between sowing date and harvest) for each class are presented in the figure 2 (map on the left). The obtained values varied significantly from class to class, between 150 mm and 330 mm, and they are proportional to the maximum value of LAI. The later was higher for the early sowing dates.

The obtained evapotranspiration map (figure 2) shows the heterogeneity of the studied area. However, a clear linear relationship between the cumulated evapotranspiration and the final biomass was obtained (figure 2, on the right); the determination coefficient R^2 is close to 1.

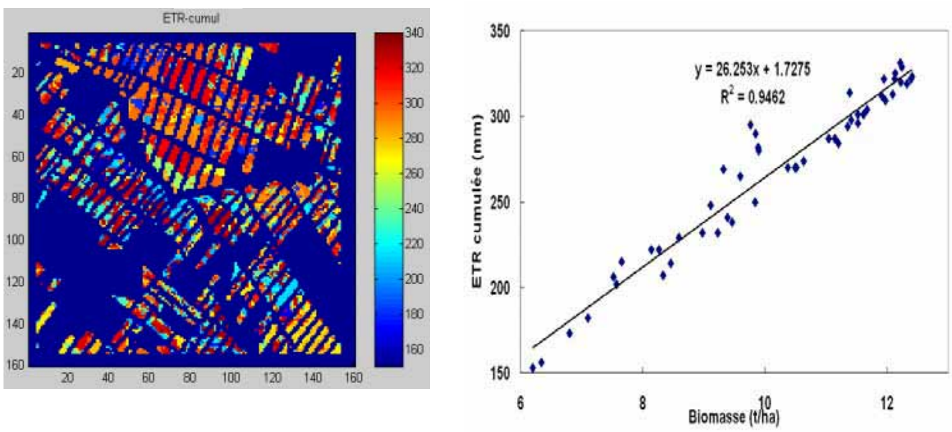
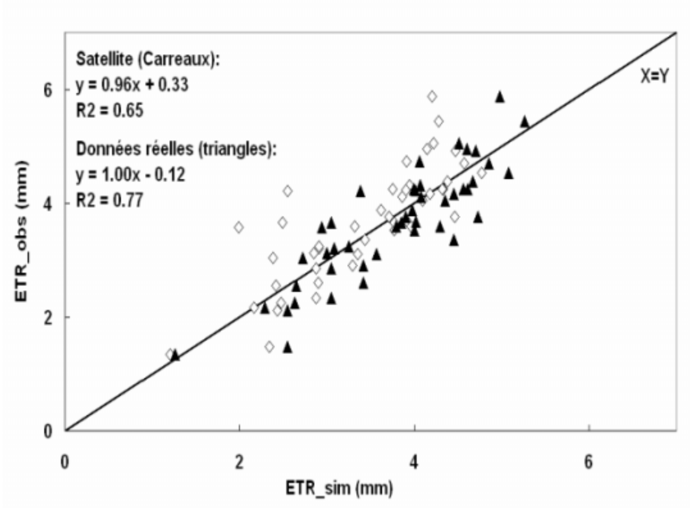


Figure 2. The cumulated evapotranspiration for the 50 classes (map on the left) and its relationship with the final biomass (curve on the right).

The accuracy of the evapotranspiration estimates was tested using the daily values collected in one controlled plot. Thus, the figure 3 shows a comparison between the measured values of real evapotranspiration and those calculated using observed input data in one hand and using input data from remote sensing in second hand. The obtained evapotranspiration from satellite data are slightly lower than those obtained using the real observations; the values of RMSE are 0.62 and 0.49 mm respectively. This was explained by the higher amount of water irrigation used for the controlled plot (180 mm) than that really used in all studied



area (120 mm).

Figure 3. Comparison between the daily measured evapotranspiration, in one controlled plot, and those calculated using observed input data in one hand and using input data derived from remote sensing in other hand.

3.1.5 Grain and biomass yields

Figure 4 presents the grain yield and total biomass simulated for the 50 classes. It shows that the variability of grain yields is very low when compared to the biomasses one. Simulated biomasses (map on the right) vary with a factor of 50% (from 6.2 to 12.4 t/ha). This variation is attempted since the simulation of biomass in STICS is directly linked to the leaf area index values via the intercepted radiation by the foliage.

In this work, the remote sensing data were used to spatialize the crop STICS model. The first test, on one plot data, shows an accurate estimation of the evapotranspiration and yield, in spite of the simplicity the assumed hypothesis. This is an important step towards the monitoring, in a large scale, of yield and water balance as well as the scheduling of irrigation in the Haouz plain using the STICS model. Evapotranspiration is the dominant loss term of the soil water balance in semi-arid areas, while water stress is an important limiting factor of crop production, especially when it occurs during the period from flowering to grain filling.
The main limits of the developed method are the difficulty to obtain some STICS input related to agriculture management (date and amount of nitrogen supply, irrigation ...).

3.2 FAO model

3.2.1 ALADIN model description

The ALADIN model is a spectral model of numerical forecast in a limited surface, based on assimilation of daily measurements, and driven using the outputs of the ARPEGE global model (provided by French meteorological services). It is an operational tool in the limited area modelling in Central Europe, and it is also used in several other regions (Morocco and Tunisia). The global model (ARPEGE) provides the data at resolution of 20 Km in France to 250 Km in antipodes, while the local model (ALADIN) worked with a higher spatial resolution (16.7 Km). The ALADIN model outputs include the climatic parameters needed for ET_0 estimate in each grids points (**Figure 4**). For the spatial distribution of ET_0, we used the simple equation proposed by the Hargreaves and Samani, 1985, the advantage of this method is that it used only the air temperature which is available at most classical weather stations world-wide.

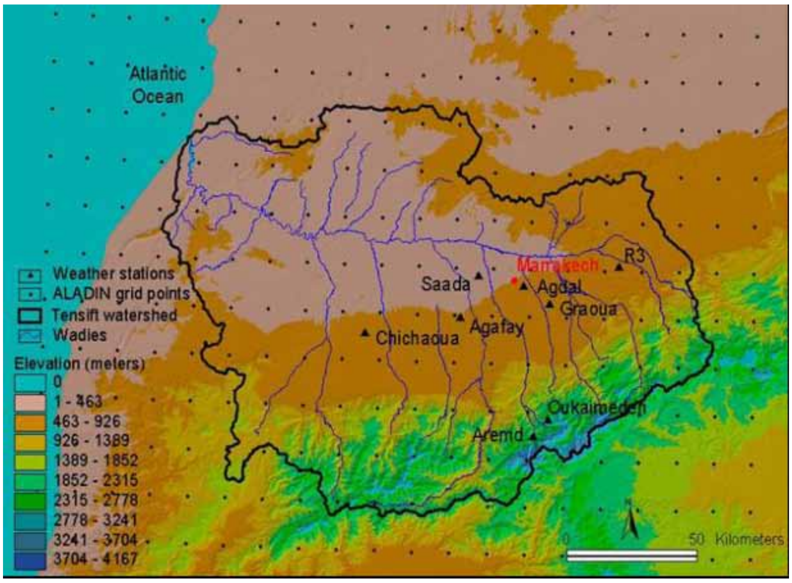


Figure 4. Study area and location of the ALADIN grids points.

3.2.2 Spatially modelling of ET_0

Figure 5 shows the cumulative monthly ET_0 (mm/month) maps for the Tensift basin by applying the HARG model to each grid point of the ALADIN model from January to December 2004. This figure exhibits a coherent spatial and temporal variation of ET_0. Temporally, the ET_0 appears to be the highest in the summer (June, July and August), ranging from 45 to 230 mm per month when it is at the peak period of air temperature, and the smallest ET_0 in November, December and January (16-68 mm per month). Spatially, the higher ET_0 is observed in the low altitude (like Haouz plain), and lower ET_0 is encountered in the mountain when the altitude is high and air temperature is low. It should be mentioned that the lower values of ET_0 are observed over the sea and over the mountain when the snow falls.

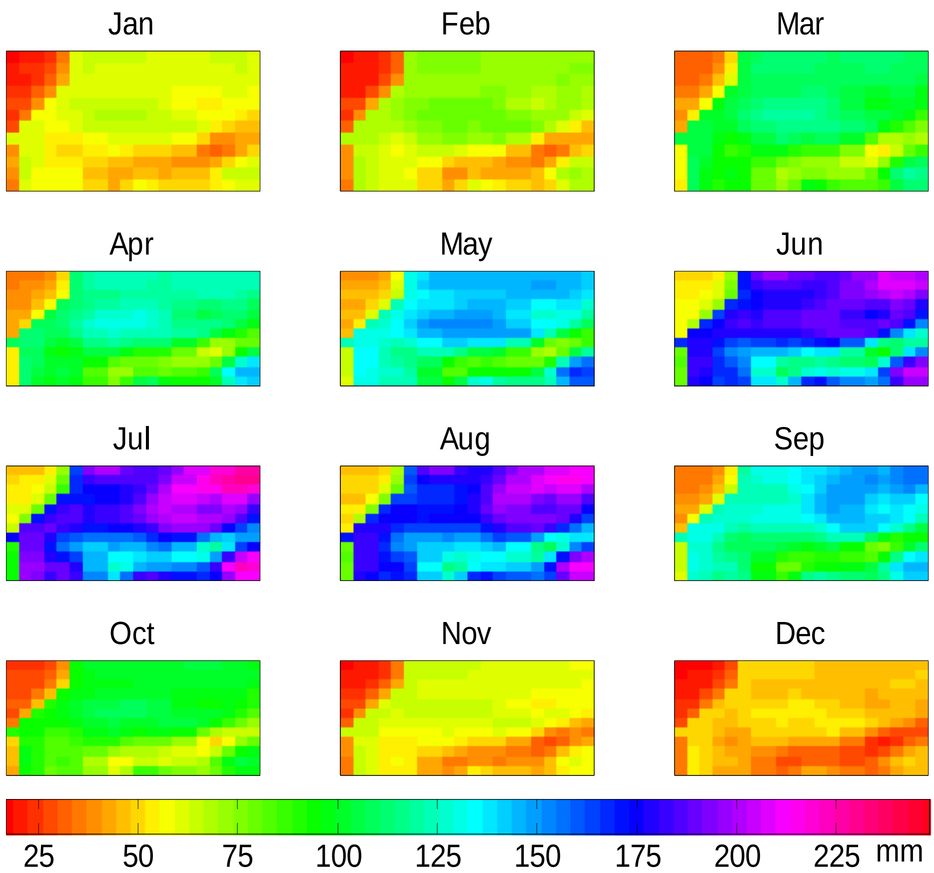
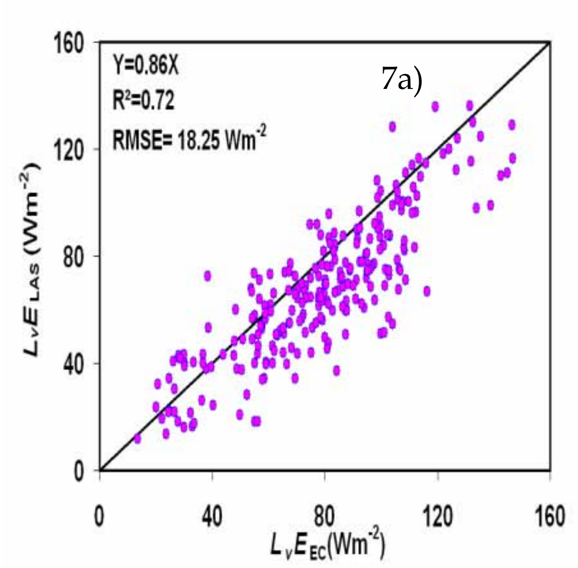


Figure 5. ET_0 (mm/month) maps for the Tensift basin obtained by applying the HARG model from January to December 2004

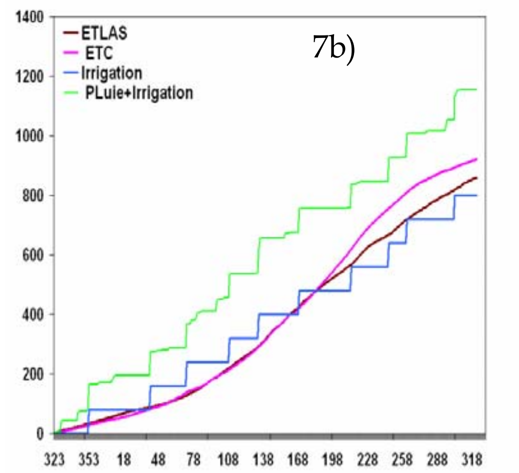
<u>Work Package 4</u>: End-user requirements and operational tools specification

4.1 The use of the Scintillation Technique for Monitoring Seasonal Water Needs and Consumption of crops in Marrakech region (Semi-Arid Region

To monitor the seasonal water needs and Consumption of crops in Marrakech region (Semi-Arid Region), a Large Aperture Scintillometer (LAS) was operated continuously more than one year over a tall and sparse irrigated oliveyard located in Marrakech (Morocco). Scintillometer based estimates of daily latent heat flux (L_vE_{LAS}), obtained by using the available energy estimates, were compared against those measured by the classical eddy covariance (EC) method (L_vE_{EC}) (see figure 7a). An underestimated of 18% and large scatter (R^2 = 0.72 and RMSE = 18.25Wm^{-2}) when we compared the LAS against the EC. This scatter explained by different factors: the difference in terms of the source areas of the LAS and EC; the closure failure of the energy balance of the EC, and to error in available energy estimates. Additionally, the irrigation efficiency was investigated by comparing measured seasonal evapotranspiration values to those recommended by the FAO-56. It was found that the visually observing the physical conditions of the plant is not sufficient to efficiently manage the irrigation, a large quantity of water is lost (≈37% of total irrigation), and a stress was occurred in DoY 190 (figure 7b). Consequently, the LAS can be considered as a potential useful tool to monitor the water consumption in complex conditions.



Comparison between daily observed (derived from EC system L_vE_{EC}) and simulated evapotranspiration (derived from the LAS using the estimated available energy, L_vE_{LAS}).



Accumulated crop evapotranspiration derived from FOA-56 (ET_c), Evapotranspiration derived from the LAS (ET_{LAS}), irrigation applied by the farmer and sum of irrigation and rainfall.

4.2 SAMIR” (SAtellites Monitoring Irrigation)

A novel operational tool “SAMIR” (SAtellites Monitoring IRrigation) has been developed for management of irrigation water at large scale. The constructed of this tool is based on satellites data and FAO-56 model. In the future, SAMIR will be able to use atmospheric forcing parameters simulated with weather prediction models to predict water needs up to several days. This will indeed represents a major tool for managing water based on demands instead of the availability.

<u>**Work package 7**</u>**:** Capacity building/ensuring sustainability

During this project, PhD students, young scientists and engineers have benefit from several training sessions in remote sensing, geographic information system, and micrometeorology, which are organized either in Morocco or in the foreign countries associated with irrimed project (France, Jordan, Syria).

Publications and Dissemination of Results

Khabba, S., Duchemin, B., Lahrouni, A., Hadria, R., 2005. Evaluation de la transmittance d’un couvert d’olivier. 7ème Congrès de Mécanique, Casablanca, 20-21 Avril 2005

Khabba, S., Duchemin, B., Lahrouni, A., Boulet, G., Hadria, R., Er-Raki, S., 2006. Evaluation de l’indice foliaire d’un couvert d’oranger. Congrès International sur la Gestion Intégrée des Ressources en Eaux et Défis du Développement Durable (GIRE3D), Marrakech, 23-25 mai 2006.

Er-Raki, S., Chehbouni, G., Guemouria, N., Ezzahar, J., Chehbouni, A., Hadria, R. 2005. Détermination des besoins en eau des cultures de la région de Tensift Al Haouz. 2ème

Congrès Méditerranéen "RESSOURCES EN EAU DANS LE BASSIN MEDITERRANEEN : WATMED 2", Marrakech (Maroc), 14 -17 Novembre 2005.

Er-Raki, S., Guemouria, N., Chehbouni, G., Ezzahar, J., Hadria, R., Chehbouni, A., 2006. Assesing water cunsumption of olive orchards in a semi arid region (Marrakech, Morocco). 1èr Congrès national sur l'Amélioration de la Production Agricole (APA), Settat (Maroc), 16-17 Mars 2006.

Er-Raki, S., Chehbouni, G., Guemouria, N., Duchemin, B., Ezzahar J., Hadria, R. 2007. Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region. Agricultural water Management journal 87, 41-54.

Ezzahar J., A. Chehbouni, J.C.B. Hoedjes, S. Er-raki, R. Hadria, Ah. Chehbouni, S. Khabba and N. Guemouria: The use of the eddy covariance technique for estimating and monitoring water consumption of olive orchards in a semi-arid region (Morocco). "Premier Congrès National : Amélioration de la Production Agricole (APA) "16-17 Mars 2006. Settat, Maroc.

Ezzahar J., Ah. Chehbouni, A. Chehbouni, J.C.B. Hoedjes, S. ER-RAKI and N. Guemouria: Estimating and Monitoring Seasonal Water Consumption of Olive Orchards in a Semi-Arid Region (Morocco) using the Eddy-Covariance System. Soumis à la troisième Conférence Internationale sur les ressources en Eau dans le Bassin Méditerranéen, Tripoli, Liban 1-3 Novembre 2006.

Ezzahar J., A. Chehbouni, J.C.B. Hoedjes, S. Er-Raki, Ah. Chehbouni, G. Boulet, B. Duchemin, A. Olioso and J. A. Sobrino: The use of the Scintillation Technique for estimating evapotranspiration ET over several agricultural fields "2nd International Symposium Recent Advances in Quantitative Remote Sensing " Torrent (Valencia), Spain, 25-29 September 2006.

Ezzahar J., A. Chehbouni, J.C.B. Hoedjes, S. Er-raki, Ah. Chehbouni and R. Hadria: Interannual and seasonal variation in evapotranspiration, sensible heat flux and energy balance in olive orchard under traditional irrigation. "International Congress Integrated Water Resources Management and Challenges of the Sustainable Development" 23-24-25 May 2006. Marrakesh, Morocco.

Ezzahar J., A. Chehbouni, J.C.B. Hoedjes, Ah. Chehbouni, S. Er-Raki, N. Guemouria, and R. Hadria: The use of the eddy covariance technique for estimating and monitoring water consumption of olive orchards in a semi-arid region (Morocco). 2ème Congrès Méditerranéen "RESSOURCES EN EAU DANS LE BASSIN MEDITERRANEEN : WATMED 2", Marrakech (Maroc), 14 -17 Novembre 2005.

Ezzahar J., Chehbouni A., Hoedjes, J.C.B., Er-raki S., Chehbouni Ah, and J-M Bonnefond, H.A.R. De Bruin, 2007. The use of the Scintillation Technique for estimating and monitoring water consumption of olive orchards in a semi-arid region, Agriculture and water management, 8 9, 1 7 3 – 1 8 4

Ezzahar J., Chehbouni A., Hoedjes J.C.B, Chehbouni Ah., 2007, On the application of scintillometry over heterogeneous grids, Journal of hydrology, 334, 493– 501.

E.7 Report of partner 7 (ORMVAH, Morocco)

The present report established according to the terms of the contract n° ICA 3-2002-10080, presents the contribution of the ORMVAH to the IRRIMED activities for the whole project duration (April 1st 2003 to March 31st 2007).

E.7.1 Work package 1: Building the information system:

In order to build the background information system needed for the project, the ORMVAH has provided the project team (partners 1 and 6) with a data set including several shape files available within the existing GIS at the ORMVAH describing irrigated areas, irrigation network, infrastructures (roads, cities), hydrographic network, pedology map, administrative boundaries (see the 1st-annual-report).

In addition, in interaction with WP2 and WP4, other informations were needed and were also provided such as a map in paper format of the agricultural development centers (CMV[9]) limits and an AUTOCAD file describing a map showing the farm units for the test site R3 (*See in annex an example of the GIS outputs:Fig.1*).

E.7.2 Work package 2 : Field micrometeorological measurements :

The ORMVAH own a network of rainfall and climatic station installed in its action zone *(see the map presented in annex: Fig.2*) which provides daily reference evapotranspiration ETo values calculated with the Penman-Monteith method. This information allow to determine the crop water requirements using the FAO model (ETR=Kc x ETo). Another agrometeorological station was purchased by the IRRIMED budget and was installed at the CMV 427 Sidi Abdellah Ghyat.

Throughout project duration, the ORMVAH has fed, and regularly update the IRRIMED project database with the hourly and daily climatic data collected by four automatic weather stations and the rainfall records collected by 23 stations overall the Haouz irrigated area. In addition, informations needed to calibrate and validate water balance models, ETR spatialisation were also provided. It concerns the monthly water irrigation quantities supplied by the ORMVAH to the different irrigated areas and the irrigation network efficiencies for the period 2000-2006.

Otherwise, to disseminate the information collected (Temperature, relative humidity, radiation, ETo, rainfall) to the farmers in order to allow them controlling and scheduling irrigation in a better way, a weekly irrigation advisory bulletin is established and posted locally at the CMV.

As a first step of improving the current dissemination system, an electronic luminous display for agrometeorological data necessary for irrigation scheduling and crop development

[9] CMV: Centre de mise en valeur agricole (Agricultural development and irrigation management district)

monitoring has been acquired and installed at the CMV Saâda. This aims to support the farmers, in the N'Fis irrigated area, in fine-tuning their on-farm irrigation management. The device was installed and made visible to the targeted public and display daily data concerning max, min and average temperature, average relative humidity, rainfall and reference evapotranspiration ETo (penman-monteith). Farmers were informed about the data displayed and the way to use it to schedule irrigation on their farms (*see Fig.3 in annex*).

Also, within the project framework, in order to make the meteorological information available at real-time for the farmers, the connexion of the existing agrometeorological stations (CAMPBELL) to the local computers was achieved.

E.7.3 . Work package 5 : Building and testing scenarios

In Haouz region, water consumption has significantly increased over the last decades while available water resources are becoming increasingly scarce especially due to climate change and drought. This increase in water demand has generated conflict for water in this region between economic sectors such as agriculture, urban and tourism. In this context, an improvement of water management in agriculture, traditionally considered as the biggest water consumer, has become necessary. This could be achieved by the conversion, overall the Haouz irrigated area, of the traditional flood irrigation, which generates almost 50% of water loss, to a new more efficient technique. The drip irrigation represents a good alternative allowing significant water saving and improvement of crops productivity.

Therefore, to test this technique and demonstrate to farmers its benefits, the ORMVAH has conducted during three years (2004-2006), experiments in the experimental station Saada of the drip irrigation on wheat. According to the findings of the model development (WP3), it appears that FAO56 method, both simple and dual approach, estimates correctly the ETR using locally adjusted Kcs on the Moroccan test site. So, considering this result and the adaptability of the method to farmers skills, the water balance method based on FAO56 model for ETR estimation was adopted to schedule irrigation.

Another experiment conducted during the 2004-2005 agricultural season, aims to compare two methods of wheat irrigation monitoring: the method carried out by the ORMVAH and FAO method known as ' Dual crop coefficient approach'.

Finally, as a result of the interaction between project partners in Morocco and according to the project objective, that is to specify operational tools to assess crop water use and requirements tailored to endusers needs, a software prototype dedicated to assist irrigation management (SAtellite Monitoring of IRrigation, SAMIR) have been developed.

E.7.3.1 -Drip irrigation on wheat experiments summary

The issue concerning the drip irrigation on wheat and its impact on the yield performance and water saving was addressed by the ORMVAH during three years by carrying out experiments in Saâda experimental station (*see Fig.4 in annex*).

The average amount applied by irrigation is about 3370 m3/ha (*for details see Table 1 and 2 in annex*). From the results obtained, it could be inferred that drip irrigation allow a water saving of almost 1500 m3/ha (30%) in comparison with the flood irrigation adopted by farmers in the irrigated area with an yield increase of about 156%. These interesting results demonstrate the positive impact of drip irrigation in water use efficiency and crop productivity improvement. However, other factors could explain the big differences between the results obtained from the experiments and those of the farms in Saada irrigated area. Indeed, in the experiment site, the other crop management factors (soil preparation, fertilization, …) were optimised which is not the case for all farmers in this region.

E.7.3.2 comparative test of two irrigation scheduling methods on wheat

The main objectives of this experiment were:

- To evaluate the impact of the irrigation monitoring method adopted by the ORMVAH in the N'Fis irrigated sector on the wheat yield and water saving by mean of a comparative test of the ORMVAH's method and the FAO method known as "*Dual crop coefficient approach*";
- To compare the results, in terms of yield improvement and water saving, obtained by the flood irrigation and the drip irrigation on wheat. The two techniques were monitored according to the FAO model.

Methodology

(*see third-annual-report of partner 7 for details*).

The first site with flood irrigation was divided into 4 plots for two treatments (ORMVAH's method and FAO method) with two replications. With the first treatment, the irrigation is scheduled according to the ORMVAH's irrigation planning adopted for the N'Fis irrigated sector. Whereas the irrigation for the second treatment is scheduled using the FAO method.

The drip irrigation on wheat was conducted on a second site using the water balance method with the FAO method to estimate crop evapotranspiration.

All the plots have the same characteristics, and the other crop management factors (soil preparation, fertilization…etc) were identical for both. The only factors which varies relates to the dates of irrigation and amounts of water applied (*see Fig.5 in annex*).

The observations and measurements made concerns:
- ***LAI estimation :*** using the hemispherical photo method,
-***Crop Phenology :*** Field measurement of NDVI was conducted with the Cropscan multispectral radiometer (MSR 87)

- *FAO model parameters :* The FAO model software proposed in annex 8 of the FAO-56 paper was adapted and used for the irrigation scheduling. The Basal crop coefficient Kcb and fraction cover f_c were evaluated using the NDVI measurements and the calibrated relations obtained on the R3 irrigated sector from researches carried out within IRRIMED project (S. Er-Raki et al, 2005):

$$K_{cb} = 1.64[NDVI - NDVI_{\min}]$$

$$f_c = 1.18[NDVI - NDVI_{\min}]$$

where : NDVImin : NDVI value for the soil.

The daily climatic parameters were obtained from the nearby automatic weather station.

E.7.3.3 Main results

- Water consumption

The water quantities applied by irrigation were 455, 396 and 362 mm respectively for the FAO and ORMVAH treatments with flood irrigation and drip irrigation treatment (*see table 3 in annex*).

For the flood irrigation, two main differences were observed during the crop season between the two treatments. It concerns for the ORMVAH's treatment, firstly, the delay in the irrigation on February, and then, the amount of water applied on March since FAO model recommended to apply a quantity twice higher than what was really applied. This had a sensible effect on the crop development and then on the yield.

In addition, drip irrigation scheduling was found to be more efficient with a water saving of about 20% in comparison with the flood irrigation scheduled according to the FAO method.

- Grain yield

Measurements of grain yield after harvesting were made in each of the treatments. The yields obtained were respectively about 50, 40 and 62 Q/ha respectively for the FAO and ORMVAH treatments with flood irrigation and drip irrigation treatment (*see table 4 in annex*).

The grain yield obtained with drip irrigation was 24% higher than with flood irrigation. Whereas in flood irrigation, it was observed that when the irrigation is scheduled according to the FAO method, there was a significant improvement in the crop yield. Indeed, the yield improvement obtained is about 28% in comparison with the ORMVAH's irrigation scheduling method. This could be explained by the crop stress induced by the delay in the date of irrigation on February and the insufficient quantity applied in March affecting grain formation.

- Crop coefficients

The basal crop coefficient Kcb derived from the NDVI measurements and the Kcb-NDVI relationship previously defined, whereas the evaporation coefficient Ke and the stress coefficient Ks were calculated by the model. In addition, the FAO model software was used to simulate the irrigation scheduling by integrating parameters concerning the ORMVAH's treatment (dates of irrigation, amount of water applied, Kcb, fraction cover, crop height, root depth) (*see table5 in annex*).

In the figure 6 presented in annex, which represents the stress coefficient Ks curve calculated for the two treatments, we can notice the crop stress occured on February when Ks reached a value of 0.37 under the limit allowable.

E.7.3.4 Operational tool on Satellite Monitoring of Irrigation

According to the ORMVAH requirements and expectations expressed in the first year of the IRRIMED project, especially concerning the need for a decision-making support tool on water resources management, the SAMIR software, "Satellite Monitoring of Irrigation", has been designed through a dialog between the ORMVAH and the IRD staff to help irrigation monitoring, based on the use of remote sensing.

The objectives of this tool are the:

- Estimation of evapotranspiration and water balance of the crops
- Estimation of the water needs and consumption, from daily to annual forecast
- Spatialisation of ETR and water balance.

Based on the FAO-56 method to estimate evapotranspiration, the application includes two main modules. The *"CLIMATE"* module allow to evaluate the reference evapotranspiration ETo by mean of three options according to the quality of the data available:

- *Climatic statistics* : spatialized climatic statistics are obtained from the *LocClim1.0* application (FAO). SAMIR tool define a grid to extract interpolated variables necessary to evaluate Penman-Monteith ETo;
- *Meteo stations* : the daily information provided by the meteo stations installed in the area of study are used to calculate the ETo;
- *Meteo model* : for daily spatialized information we can use the national meteorological model which propose 6 hours-data from a grid of 16*16 km.

The "*VEGETATION*" module allow to define the land cover of the area of study and also the crop coefficients of the predefined crop classification. Three options are possible:

- *Surface statistics* : The user must provide the application with the informations concerning the surfaces of crops existing in the area of study. No spatialization is possible with this option. The crop coefficients are those defined in the FAO-56 paper or those adjusted for the specific region;
- *Landuse maps* : The principle is to provide the user by a landuse map if the satellite images are not available. This landuse map is derived from a satellite image over previous years. Also in this case, the crop coefficients are those defined in the FAO-56 paper or those adjusted for the specific region;
- *NDVI maps* : the landcover is defined from satellite time series after a NDVI time profiles classification. The crop development coefficients used by the FAO method (Kc) are derived from NDVI time profiles using calibrated relations, and considering the land cover class of each pixel.

The main outputs of the SAMIR tool could be of two sorts : synthetic graphs representing the crop water needs, or evapotranspiration maps over the area of study depending on the data quality available and the user choices (*see illustration in partner 1 report*).

The ongoing development of this tool concerns a full water budget assessment by introducing a soil module with irrigation / rainfall inputs and also forecasting capabilities development. It is expected in the long-term to integrate SVAT models and simulation module enabling to built up and test scenarios.

E.7.4 Work package 6: End user requirements and specifications

In interaction with project partners, specially scientists from IRD team and FSSM in Morocco, the ORMVAH requirements and expectations from the project were identified and discussed in order to match between the project scientific results and the end-user needs. These requirements, which concerns the difficulties encountered in irrigation water management, were also presented in the first end users meeting held in Amman (Jordan) on 5th Decembre 2004, and can be summarized as follows, considering two levels:

- *irrigation planning on the sector level*:

currently, water allocation is made according to the water availability in a given year, and that is only used to determine the corresponding areas that can be irrigated given the estimated needs for each main crop group. The water distribution and network operation, particularly on the tertiary level, are made without any consideration to the cropped areas, crop types and their water requirements.
So, for the ORMVAH, there is a need to develop scientific and operational tools which will help in improved irrigation planning and network operation based on a better knowledge of the land cover and crop water demand.

- *irrigation scheduling on the farm level*:

Because of water scarcity, especially in the last years, a great part of the farmers use ground water as another water supply and new irrigation techniques such as drip and sprinkler irrigation. With these techniques, irrigation scheduling is very important based on a daily crop water requirement assessment.
For the ORMVAH, there is a need to offer an adequate advisory irrigation service to the farmers enabling them to better plan and schedule irrigation at the farm level. And for that, a best knowledge of the crop water requirements for different crop types and at different vegetative stages, combining with the climatic data, is very necessary.

During the second year of the project, a survey was carried out to identify the methods adopted by farmers to monitor irrigation. From the results, it can be noticed that in big farms (area >20 ha) with new irrigation techniques (drip or sprinkler systems) and individual wells, the evaporative pan is used to evaluate ETo and crop water needs. For small farms, the irrigation is monitored according to the farmer experience (farmer with own well) or the water availability when the only source of water is that supplied by the ORMVAH.

Within the project, a set of methods was elaborated and some results concerning the evapotranspiration assessment, crop development and irrigation monitoring for the main crops in the region were obtained. Therefore, the next step will be the farmers assistance and training on the use of such methods and techniques that enables them to monitor irrigation in a more efficient and a better way. For that, special tools and services using information and communication technologies (ICT) should be developed to reinforce the existing irrigation advisory service to provide farmers with the information necessary for their on-farm irrigation management. That is the objective of PLEIADeS project, funded by EC, in which the ORMVAH has been involved as partner.

E.7.5 Work package7: Capacity building ensuring sustainability

The ORMVAH team have benefited from the participation of engineers to the three training workshops, planned and organised within the IRRIMED project, on very interesting topics which are presented hereafter.

Participation in meetings including training:

Meeting	Period	Participants
Kick-off meeting, Toulouse, France	22th-23th May 2003	Eng. Ouzine Lahcen
1st annual meeting , Tunis, Tunisia	21th-23th April 2004	Eng. Cherkaoui Ikbal Med
2nd Annual meeting, Marrakech, Morocco.	13th -17th April 2005	Eng. Ouzine Lahcen, Kharrou Med Hakim, Cherkaoui Ikbal Med, Sghir Fathallah
Workshop on estimation of actual evapotranspiration and crop-water requirements. Palmyra-Syria	7th-13th February 2004	Eng. Kharrou Med Hakim, Cherkaoui Med Ikbal
Workshop on Remote Sensing Image Processing for Irrigation Monitoring: Hands on Training.	28th Nov-2th Dec 2004	Eng. Sghir Fathallah
Workshop on crop water modelling tools. Tunis, Tunisia.	28th November – 2nd December 2005.	Eng. Kharrou Med Hakim

E.7.6 - Publications and papers:

Kharrou, M. H. (2005), Pilotage de l’irrigation des céréales selon le modèle FAO, DESA thesis, 67 pp,Université Cadi Ayyad, Faculté des Sciences Semlalia, Marrakech.

Helson, D., Simonneaux V., Duchemin B., Chehbouni G., Cherkaoui M., **Kharrou H.** (2006), SAMIR, un logiciel pour la spatialisation de l’évapotranspiration par télédétection. Application à l’aide à la gestion de l’irrigation dans la plaine du Haouz, Marrakech, Maroc, in Colloque International GIRE3D, edited, Faculté des Sciences Semlalia, Marrakech, Maroc.

ANNEX

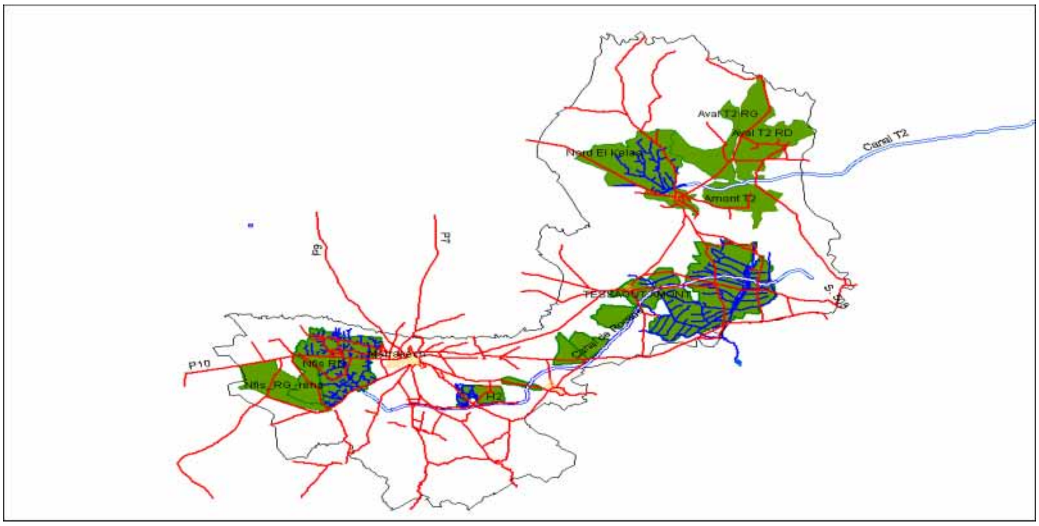


Fig. 1 : Irrigated areas and irrigation networks in Haouz plain

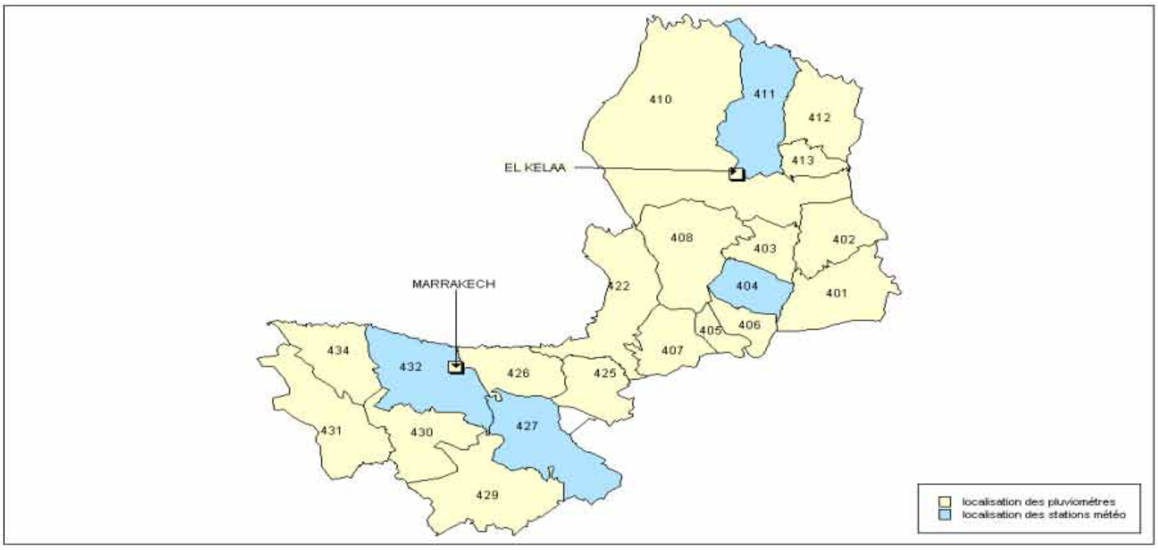


Fig. 2 :GIS map of the CMV boundaries and climatic stations location

Fig.3: The luminous display installed at the CMV Saâda

Fig. 4: the drip irrigation on wheat plot

- **Drip irrigation experiments**:

  - ***Water consumption***

Crop season	**2003-2004**	**2004-2005**	**2005-2006**
ETc (mm)	483,9	430	355.5
Rainfall (mm)	172,7	52	169,4
Irrigation (mm)	363,0	362	286

Table 1 : water consumption (mm) (drip irrigation experiments)

- ***Agronomic results***

	Test site				Average results of the Saada irrigated area			
	yield qx/ha	irrigation (m3/ha)	Production value (Dh/ha)	Water valorization (Dh/m3)	yield qx/ha	irrigation (m3/ha)	Production value (Dh/ha)	Water valorization (Dh/m3)
2003-2004	73	3630	16060	4,4	27	5200	5940	1,14
2004-2005	62	3620	13640	3,8	25	5200	5500	1,1
2005-2006	75	2860	19800	6,9	30	4200	6600	1,6

Table 2: agronomic results (drip irrigation experiments)

- comparative test of two irrigation scheduling methods on wheat:

Fig. 5: plot PG3 :flood irrigation and plot PL3 : drip irrigation

TRAITMENT	F [10]	O	Drip Irrigation
TOTAL Irrigation	455	396	362
TOTAL Rainfall	52	52	52
TOTAL	**507**	**448**	**414**

Table 3 : water consumption (mm) (irrigation scheduling methods comparison)

Traitment	F	O	Drip Irrigation
Grain yield (q/ha)	**49,8**	**39,4**	**61,73**

Table 4 : grain yield measurements (irrigation scheduling methods comparison)

Traitment	Basal crop coefficient Kcb		
	Kcb ini	Kcb mid	Kcb end
FAO traitment	**0,14**	**1,20**	**0,29**
ORMVAH treatment	**0,18**	**1,16**	**0,25**

Table 5 : Basal crop coefficient values

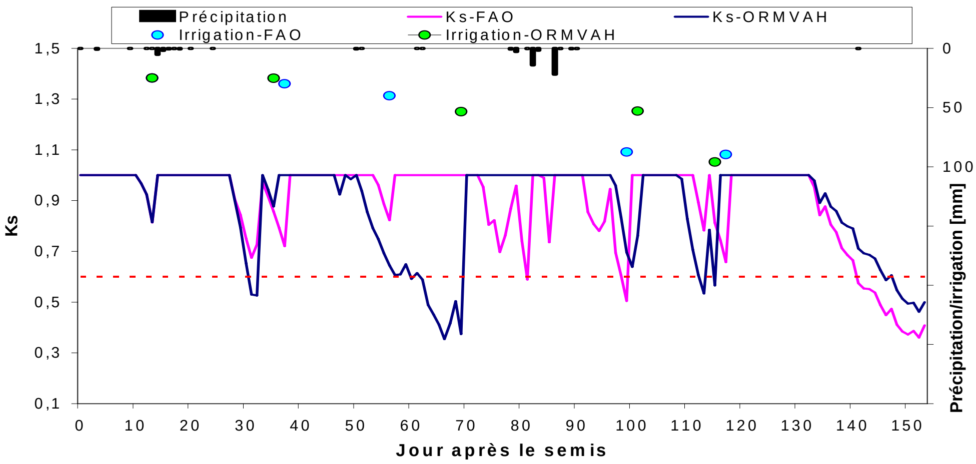


Fig. 6 : Stress coefficient Ks for the two treatments

[10] F : FAO treatment under flood irrigation; O : ORMVAH treatment under flood irrigation

E.8 Report of partner 8 (ACSAD, Syria)

Report prepared by ACSAD - IRD

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E.8.1 Study area

The study area is located in Palmyra oasis near the town of Palmyra (latitude 34º 32´ N, longitude 38 º 16´ E) in the center of the Syrian desert. The climate is Mediterranean arid . The average maximum temperature during hottest month is 37.8 C º , the average minimum temperature during the coldest month is 2.4 C º . Rain season extends from October until May with average annual rainfall of 120 mm Samaan (2005). Figure 4 shows rainfall distribution during the year of 2005. Estimated annual potential evapotranspiration is 1760 mm and pan evaporation is 2300 mm. The whole Oasis covers 1000 ha . The main cultivations are olive trees (250,000 trees), Palm trees (70,000 trees), Pompergate trees (80,000 trees) , and other fruit trees (250,000). The micrometeorological and soil moisture measurements were made in a 0.4 ha field chosen to be well representative with fetch around 1 km in every direction.

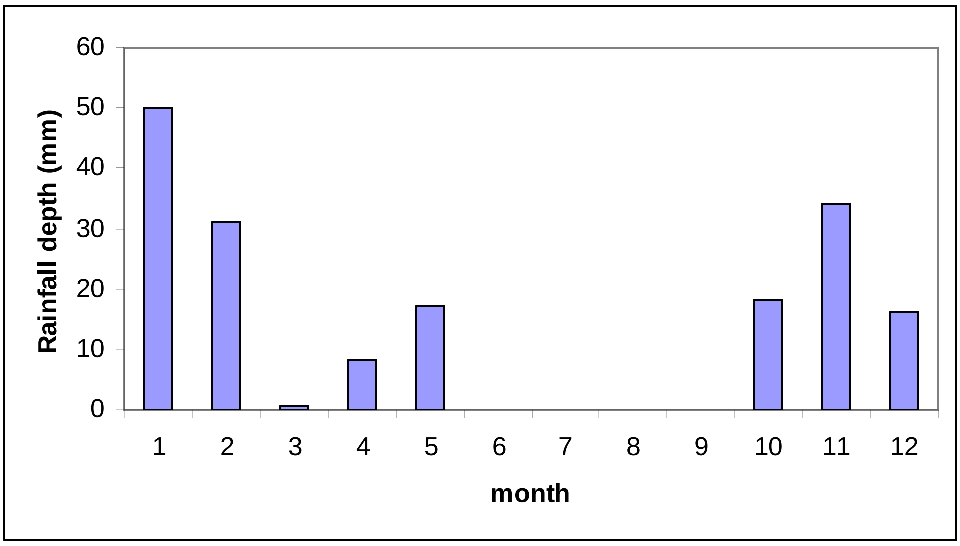

Figure1. Rainfall distribution during year of 2004

The soil texture is sandy loam to depth of 0.35 m , sandy clay loam between 0.35 m and 1.50 m and sandy clay at 1.5 m. Table 1 summarize some of the soil physical characteristics at different depths below the soil surface.

Table 1- Some of the soil physical characteristics at the experiment site.

Depth (cm)	% sand	% silt	% clay	Bulk density (g/g)	Field capacity (cm^3/cm^3)
10	73	11	16	1.41	34.6
25	47.2	9.8	16	1.37	28.5
50	65.4	11.6	23	1.21	25.9
75	54.4	14.6	31	1.10	28.1
100	55.2	14.8	30	1.18	32.3
125	50.2	16.8	33	1.18	30.2
150	46.4	18.4	35.2	1.13	28.1

The oasis is irrigated with traditional flood irrigation method. Water is delivered to the farmer once a month from a governmental public well. However, some farmers have their own wells and they apply additional irrigation to their farm land. Table 2 presents the irrigation schedule and amount of irrigation during the year of 2005 applied to the 0.4 ha field in which the instruments were installed.

Table 2- applied irrigation water during year of 2005

Date	**Total applied volume (mm)**
18/3/2005	77
26/3/2005	79
28/5/2005	63
17/6/2005	98
28/6/2005	70
15/7/2005	51
31/7/2005	129
17/8/2005	53
1/9/2005	66
2/10/2005	67
3/11/2005	65
4/12/2005	96
31/7/2005	129
Total	1043

E.8.2 Eddy covariance measurements

Eddy covariance instruments were mounted on a tower 5 m above the trees canopy. The system consist of a CSAT3 three dimensional sonic anemometer (Campbell sc.) and a KH20 Krypton hygrometer (Campbell sc.). The three dimensional sonic anemometer in which ultra sonic signals are pulsed between three pairs of transducers is used to determine vertical wind speed. The Krypton hygrometer measures the water vapor density. These instruments were scanned every 0.15 sec and the vertical wind speed and vapor pressure are averaged every 15 min and logged into a CR23 X data logger (Campbell sc.).

The eddy covariance measurement point corresponds to fetch of 200 m. Evapotranspiration (ET_{eddy}) is calculated from the following equation

$$ET_{eddy} = \rho\lambda \operatorname{cov}(w'q') \qquad (1)$$

Where

ET_{eddy} *is the e* vapotranspiration calculated from eddy covariance method (mm/day)

λ is the latent heat of vaporization of water

ρ is the density of air

w' is the deviation in vertical wind speed from average vertical wind speed

q' is the deviation in specific humidity of air from average specific humidity of air

The sensible heat flux was calculated as

$$H = \rho\ c_p \operatorname{cov}(w'T') \qquad (2)$$

Where

c_p is the specific heat of air

T' is the deviation in temperature of air from average of air temperature

Air temperature were measured using the sonic anemometer

In addition to eddy covariance measurement above the canopy, temperature and relative humidity were measured using MP100A temperature and relative humidity probe. Horizontal wind speed were measured using 05103- L__ RM Young2 Wind Monitor , net radiation were measured using net radiometer. Incoming radiation were measured using NR-Lite Net radiometer (Campbell Sc.) . These instrument were installed above the conopy near the eddy covariance instruments. Moreover, two HFP01 Heat Flux plate were installed 3 cm below the soil surface. One plate was installed in an open area and the other one in shaded area below the trees canopy. These data were logod every 15 minute using CR10X datalogger.

E.8.3 Soil moisture measurement;

In the same field the eddy covariance system was installed, seven 30 cm TDR probes (CS616, Campbell Sc.) were used to measure volumetric moisture content. The probes were buried horizontally at depths of 0.1, 0.25, 0.5, 0.75, 1, 1.25, and 1.50 m below the soil surface. The TDR probes were connected to a CR10X data logger (Campbell Sc.) and soil moisture measurements were recorded every hour. Soil matric potential was measured with mercury Tensiometer (STM 2150, SDEC FRANCE). Seven tensiometers were installed at similar depths as the TDR probes. The tensiometers readings were taken manually on daily basis. The TDR readings were calibrated using gravimetric method. soil samples were taken at different times and at depths similar to that the TDR sensors were installed at. The soil moisture content of the obtained soil samples were determined on mass basis (θ_m)using oven method . The volumetric water content (θ_v) was obtained by multiplying θ_m by soil bulk density.

Calculating ET using climate based evpotranspiration model

three models were selected to estimate evapotranspiration : FAO Penman-Monteith, Turc, and Hargreaves.

The FAO Penman-Monteith method is given as.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (3)$$

Where :

ETo reference evapotranspiration [mm day-1],
Rn net radiation at the crop surface [MJ m-2 day-1],
G soil heat flux density [MJ m-2 day-1],
T mean daily air temperature at 2 m height [°C],
u2 wind speed at 2 m height [m s-1],
es saturation vapor pressure [kPa],
ea actual vapor pressure [kPa],
es-ea saturation vapor pressure deficit [kPa],
Δ slope vapor pressure curve [kPa °C-1],
γ psychrometric constant [kPa °C-1].

The Hargreaves *ETo* models is given as

$$ETo = 0.0023(T_{mean}+17.8)(T_{max}-T_{min})^{0.5}Ra \qquad (4)$$

Where
T_{mean} is the mean air temperature [°C],
T_{max} is the maximum air temperature [°C],
T_{min} is minimum air temperature [°C],
Ra is extraterrestrial radiation [MJ m^{-2} day^{-1}],

The Turc model (Turc ,1961) is given as

$ETo = 0.313\ T_{mean}\ (R+2.1)/(T_{mean}+15)$ *(5)*

Where

Rs is the solar radiation [MJ m^{-2} day^{-1}],

The actual evapotranspiration (*ETC*) is determined from the reference evapotranspiration using the crop coefficient (*Kc*) as following

$$ETC = KcETo \qquad (6)$$

Where *Kc* is the crop coefficient

The Oasis has 70,000 trees of date Palm and 250,000 trees of olive . The crop coefficient for this mixture of tree is given as (Allen et al. 1998)

$$Kc = \frac{f_1 h_1 Kc_1 + f_2 h_2 kc_2}{f_1 h_1 + f_2 h_2} \qquad (7)$$

Where

f1 number of olive trees

*h*1 height of olive trees

Kc_1 crop coefficient for olive trees

*f*2 number of date palm trees

*h*2 height of date palm trees

Kc2 crop coefficient for palm trees

Doorenbos and Kassam (1986) state that olive state that olive are best irrigated using Kc of between 0.4 and 0.6. In Italy, Deidde et al. (1990) recommended *kc* of 0.66 for olive tree. In California, it was recommended that olive best irrigated at *kc* =0.75 (Beede and Goldhamm 1994). In Spain Pastor and Orgez (1994) have found the monthly Kc's value presented in table 3 for olive orchards having 60% ground cover . These values were considered in this study because similar ground cover presented in the experiment site.

For date palm tree (Doorenbos and Pruitt, 1977) stated that *kc* ranges between 0.8 and 1. Liebenberg and. Zaid (2002) presented monthly kc's (Table 3) varied between 0.8 and 1. These values were considered in this study.

Table 3- crop coefficient for olive tree and for date palm tree and for mixed system

month	1	2	3	4	5	6	7	8	9	10	11	12
Kc olive	0.5	0.5	0.65	0.6	0.55	0.5	0.45	0.45	0.55	0.6	0.65	0.5
Kc date palm	0.8	0.8	0.8	0.9	1	1	1	1	1	1	0.8	0.8
Kc mixed tree	0.60	0.60	0.70	0.70	0.70	0.66	0.63	0.63	0.70	0.73	0.70	0.60

As mentioned earlier climatic models estimate ET for well watered crop (i.e soil moisture ~ fc). To estimate actual evaporation fisher et al. 2005, introduced soil moisture function or stress factor as following

$$ET_{actuals} = Ks\ ET_C \tag{8}$$

Where K_S is defined as

$$K_s = \frac{\theta}{fc} \tag{9}$$

In which

θ is the measured volumetric moisture content(%),

fc is the volumetric field capacity (%)

fisher et al. 2005 used the volumetric moisture content at 20 cm depth as value for ., This might be valid for non irrigated forest, however for irrigated crop, *ks* need to be representative for the whole rooting depth. Therefore, in this study *ks* was calculated at the seven depths, the soil moisture content and field capacity were measured. Then the weighted *ks* was calculated as following

$$ks = m_1 ks_{0.10} + m_2 ks_{0.25} + m_3 ks_{0.5} + m_4 ks_{0.75} + m_5 ks_{1.0} + m_6 ks_{1.25} + m_7 ks_{1.50} \tag{10}$$

where $ks_{0.1}$, $ks_{0.25}$, $ks_{0.50}$, $ks_{0.7\ 5}$, $ks_{1.00}$, $ks_{1.25}$, *and* $ks_{1.50}$ are the stress factors calculated at depths of 0.1, 0.25, 0.5, 0.75, 1, 1.25, and 1.50 m, respectively.

m_1 , m_2 , m_3 , m_4 , m_5 , m_6 , *and* m_7 are rooting extraction ratio at depths *of* 0.1, 0.25, 0.5, 0.75, 1, 1.25, and 1.50 m, respectively.

Rooting extraction ratio at each depth was calculated as following

$$m = \frac{\Delta s_i}{\sum_{i=1}^{7} \Delta s_i} \tag{11}$$

ΔS_i is the change in daily stored soil water at depth *i* which is determined by multiplying the change in volumetric water content at depth *i* by the depth of soil layer between two successive depths. Measurement for interval during and immediately after irrigation were eliminated to avoid inaccuracy due to deep drainage

Statistics

The agreement between measured values of evapotranspiration (ET_{eddy}) and those from climatic models were quantified using the Standard Error of the Estimate (SEE) which is a measure of the scatter of the estimated evaporation around the measured evapotranspiration

$$SEE = \sqrt{\frac{\sum \left(ET_{eddy} - ET_{model}\right)^2}{n-2}} \qquad (12)$$

where, ET_{eddy} are values of measured ET using eddy covariance method, ET_{model} are values of ET determined from a climatic model,

Moreover the coefficient of determination (r^2) was determined using linear regression analysis between the measured ET value and that obtained from the climatic models. The intercept mean value (Federico saa et al. 2004 P59) of linear regression between predicted and measured ET were used also to assess the performance of different ET models. High interception means model over predicted ET during early season. Interception value close to zero are desirable. slope close to 1 indicate better prediction .

E.8.4 Results and discussion

Eddy covariance measurement

ET in the oasis were measured during 2005 between February 16 and October 8. the value of ET during this period ranged between 0.36 mm/day on February, 15 and 4.57 mm/day on Jun 28 . The total ET during the measurement period was 565 mm. The validity of eddy covariance measurement was evaluated using the Pruger et al. 1996 fraction of energy balance due to closure calculation i.e

$$\textit{Fraction closer} = \frac{LE + H}{Rn + G} \qquad (13)$$

Closer of energy balance was acceptable (slope = 094, r^2=091) (Figure 2) for the site over the measurement period. G was used as an average value by the two heat flux in the shaded and in the open area.

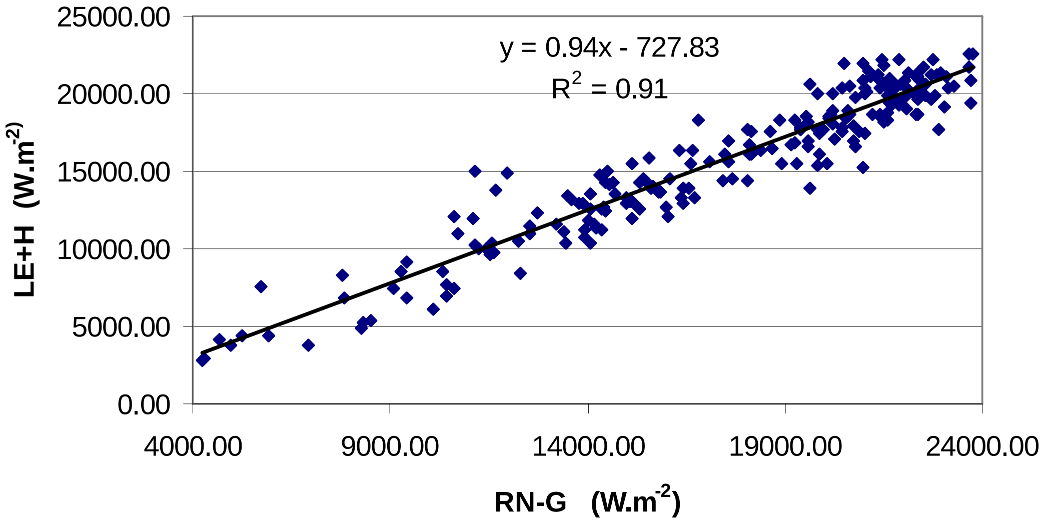

Figure 2- Energy balance closer

soil moisture dynamic

Figure 3 shows the time series of soil moisture at seven depths the TDR sensors were installed. It can be seen clearly the dynamic nature of soil moisture at the upper soil profile (measured at depths of 0.10,0.25, and 0.50 m) compared to that measured at lower soil profile (measured at depths of 0.75, 1.00, 1.25, and 1.50 m) .At the upper soil profile, soil moisture changed between less than 20 % before an irrigation event to 31 % (near field capacity) after irrigation event . The lower soil profile was less responsive to precipitation and irrigation events that the soil moisture was held near field capacity (~ 30%).

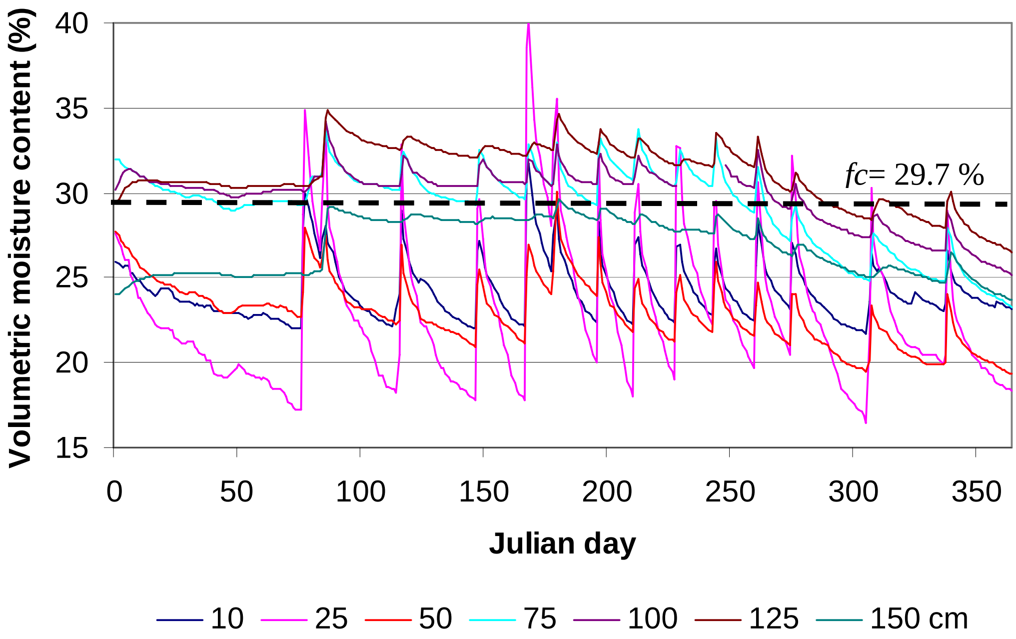

Figure 3- time series of daily volumetric soil moisture contents measured at depths of 0.1, 0.25, 0.5, 0.75, 1, 1.25, and 1.50 m.

Stress factor

Measurements of daily soil moisture content (Figure 3)shows that soil moisture content at upper soil profile were mostly below field capacity. This means the trees in the oasis experienced some degree of water stress. In order to obtain stress factor, pattern of extraction of soil water by oasis trees was obtained in the tope 1.5 m of soil profile (Figure 4). The water extraction ratio were 33, 30, 13, 10, 6, 5, and 3 % at depths of 0.1, 0.25, 0.5, 0.75, 1, 1.25, and 1.50 m respectively. It can be noted that approximately 75 % of the water uptake occurred from the top 50 cm of soil profile. This result is similar to that obtained by Gardner (1983) who developed crop extraction curve based on data from about 40 different root water uptake measurements on wide range of species.

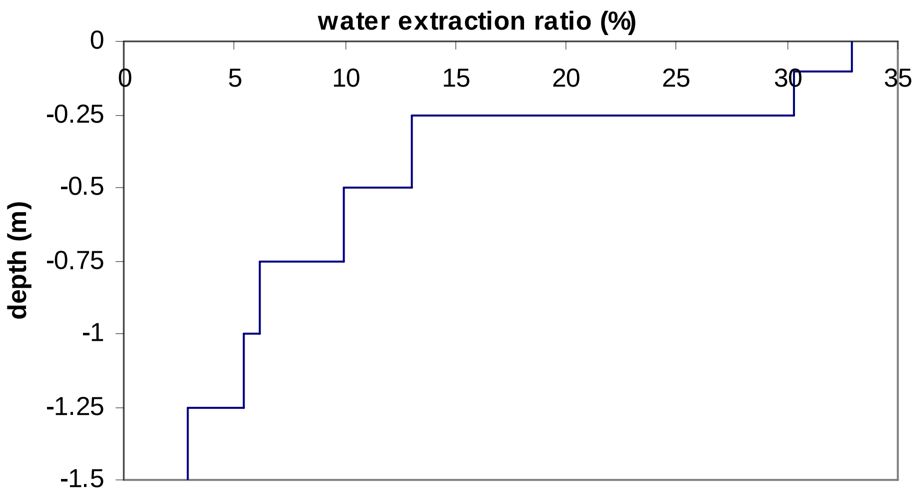

Figure 4- depth and distribution of water extraction ratio by oasis trees.

stress factor was the obtained for the top 1.5 profile based on equation 9.

. Figure 5 shows that *ks* oscillated between 0.65 and 1 with an average value of 0.77.

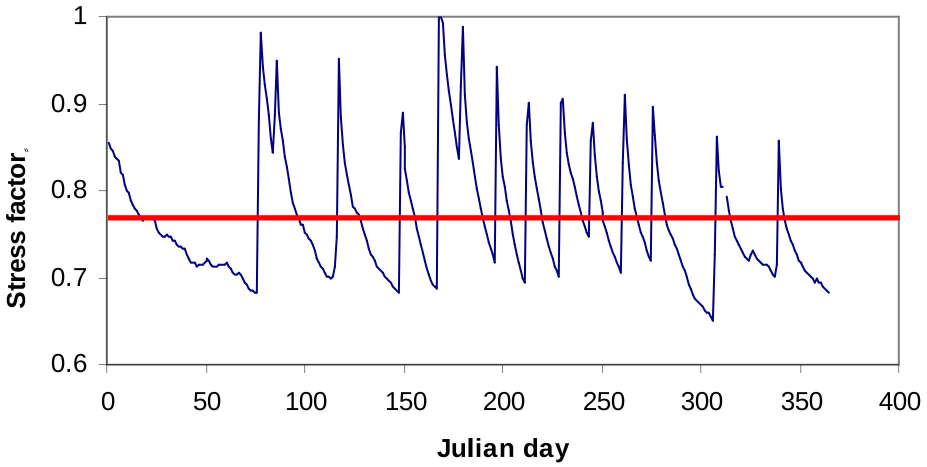

Figure5- daily stress factor

Comparing potential (ETc) and measured evapotranspiration (ET_{eddy})

Figure 6 compares the ETc calculated from the climatic equations with that measured with eddy covariance method. Throughout the study period (227 days) ET calculated from the climatic equation consistently over predicted ET_{eddy} . Total measured ET was 62, 74, 54, and 67 % of that calculated using Penman-Monteith, Turc, and Hargreaves equations, respectively. The Penman-Monteith model has the highest standard error of estimate (1.63 mm/day) ; however it has the highest r^2 value (Table 4). Turc model gave the smallest standard error with r^2 of 0.67.The shape of the ET trend obtained from the climatic models were reasonably compared to that obtained from EC method.

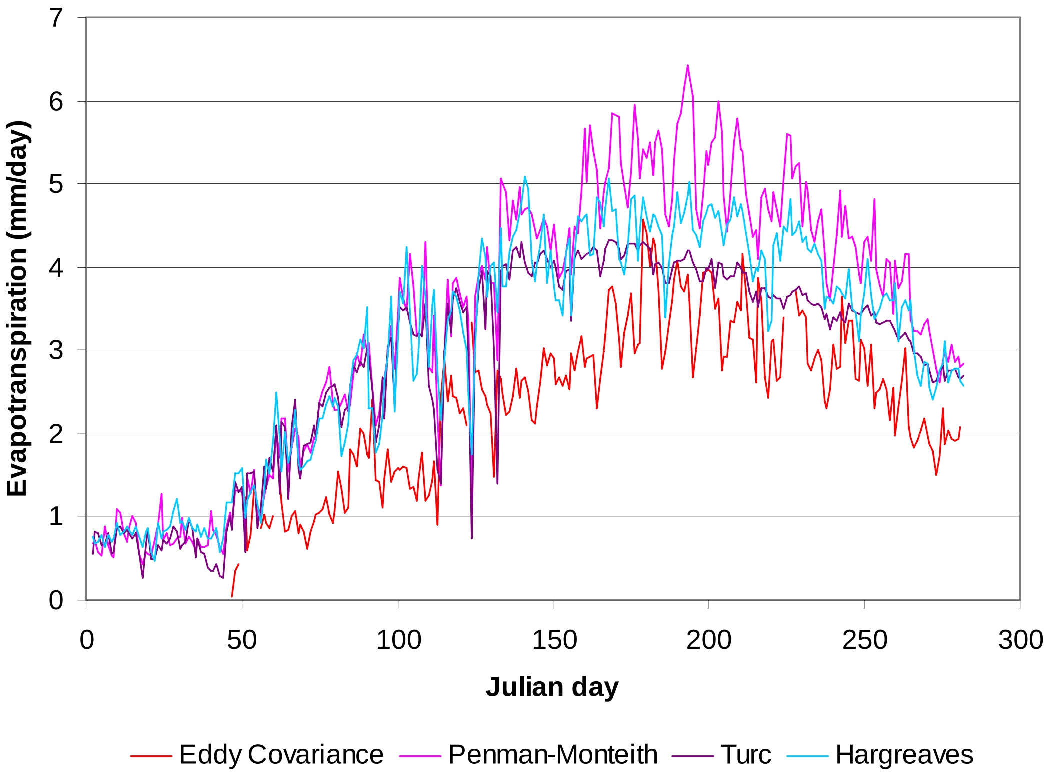

Figure 6- comparison of the ETc calculated from the climatic equations with that measured with eddy covariance method

Table 4- the standard error of estimate (SEE) and regression result of daily evapotranspiration

Model (n=227)	*SEE* (mm/day)	r^2	regression
Penman-Monteith	1.63	0.74	*1.16x+1.09*
Hargreaves	1.23	0.70	*0.91x+1.31*
Turc	1.04	0.67	*0.72x+1.56*

Comparing potential (ETc) and measured evapotranspiration (ET_{eddy})

Figure 7 compares ET values calculated from climatic equation after considering the stress factor (Eq. 8) with ET_{eddy}. all of the three models estimate were improved. The differences between total ET obtained from the climatic models and that measured with eddy covariance method was reduced from 344,199, 254 mm to 149,35, 177 mm for Penman-Monteith, Turc, and Hargreaves equations, respectively. The SES was reduced to be less than 1 mm/day for all investigated models. Turc and Hargreaves nearly approximated measured ET. However Hargreaves model has better correlation with EC (R2 =0.75 comared to R2 =0.66 for Turc models) .

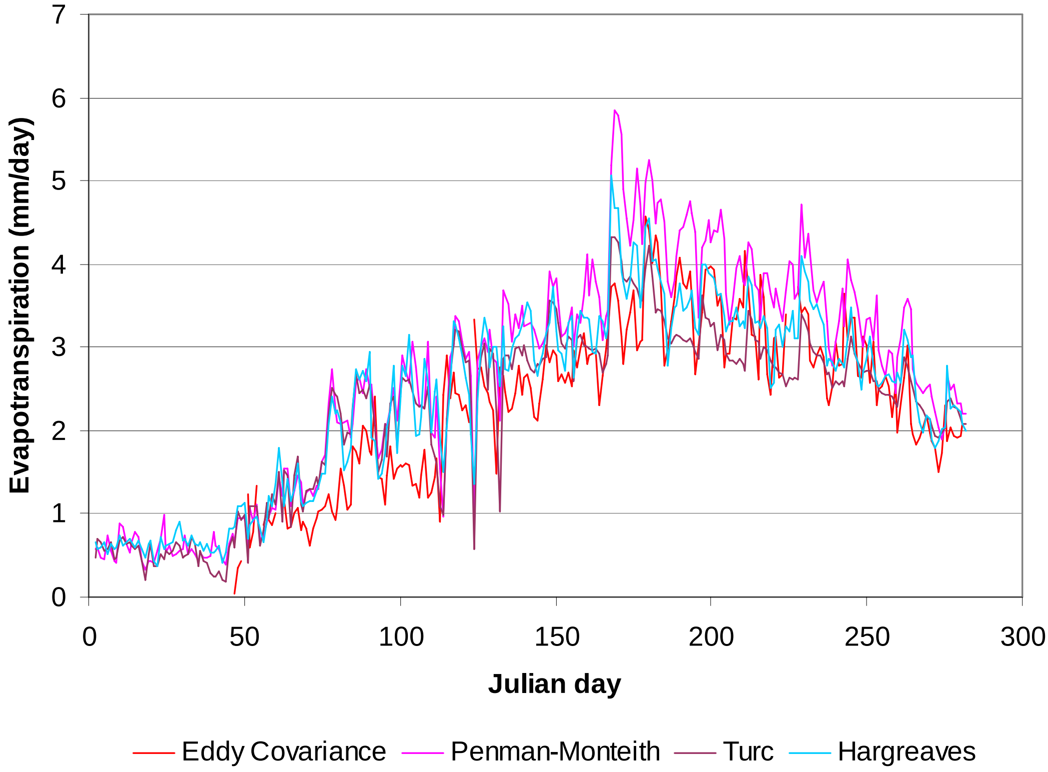

Figure 7- comparison of the ETc calculated from the climatic equations after considering the stress factor with that measured with eddy covariance method

Table 5- the standard error of estimate (*SEE*) and regression result of daily evapotranspiration after considering the stress factor

Model (n=227)	SEE (mm/day)	r^2	regression
Penman-Monteith	0.84	0.76	*1.01x+0.63*
Hargreaves	0.58	0.75	*0.8x+0.82*
Turc	0.57	0.69	*0.65x+1.03*

E.8.5 Energy Balance method for Evaporation estimation of the Syrian central desert (Sabkht Al Mouh).

Sabkht Al Mouh is located in the center of the Syrian desert near the town of Palmyra (latitude 34° 27´ N, longitude 38° 20´ E) and extend over total area of 16,000 km^2. The groundwater level in the Sabkht ranges between 0.2 and 1m below soil surface . In order to determine the water budget in the Sabkht, several studies have been done in the past to estimate direct evaporation from it . In 1995, annual evaporation from the Sabkht was determined to be about 185 mm using lysimeters method. In the year of 2000, isotope profiles in the soil of the Sabkht were made
(Zakhem and Hafez, 2000) using Barnes and Allison model (Barnes and Allison,1983) was applied for annual evaporation estimation . The model predicted annual evaporation of 75

mm in the Sebkhe. Based on these results the Syrian government has adopted a new water policy in the region for exploiting the groundwater instead to leave such volume of water evaporated .Since the groundwater in the area is nonrenewable the over pumping has led to an environmental problems. Due to the large difference in both values of evaporation previously mentioned and the need to define more preciously this volume for water development planning purpose, a micrometeorological equipment was set up in the Sabkht in 2002 for measuring radioactive budget, sensible heat flux, soil heat flux and evaporation using a simplified aerodynamic approach (Riou and Itier, 1986; Brunel, 1989). Averaged values of net radiation, gradient of wind speed and temperature, soil heat flux were made every 15' and stored on a data logger

- **Energy balance methods**

Rn – G -LE – H =0

- Rn is the net radiation,
- H the sensible heat,
- G the soil heat flux and
- LE the latent heat

RN and G are measured (figure 1) however the latent heat flux is calculated from the following equation :

$$H = -\frac{\rho C_p k^2 \Delta T \Delta u}{\left[\ln\left(\frac{z_2}{z_1}\right)\right]^2}\left[1-16\left(\sqrt{z_1 z_2}\,\ln(\frac{z_2}{z_1})\frac{g}{T}\frac{\Delta T}{(\Delta u)^2}\right)\right]^{\frac{3}{4}}$$

For *T2<T1, and*

$$H = -\frac{\rho C_p k^2 \Delta T \Delta u}{\left[\ln\left(\frac{z_2}{z_1}\right)\right]^2}\left[1-5\left((z_2 - z_1)\frac{g}{T}\frac{\Delta T}{(\Delta u)^2}\right)\right]^{2}$$

For *T2> T1*

where $\kappa = 0.4$, $g = 9.8\ m\ s^{-2}$, $c_p = 1005\ J\ kg^{-1}\ K^{-1}$, ρ is air density, T mean absolute air temperature of the surface layer, z_1 and z_2 are the levels t which the horizontal wind speed (U) is measured, and where temperature (T) are observed.

Figure 1 – equipment used in the evaporation measurement from Sabkht Al Mouh

Figure 2 shows result of the evaporation measurement during year of 2004 . the minimum value of evaporation was 0.02 mm/day recorded on August 3, while the maximum evaporation was 1.16 mm/day recorded on 13/10. the low value of evaporation during summer is due to reduction of groundwater level and soil dryness.

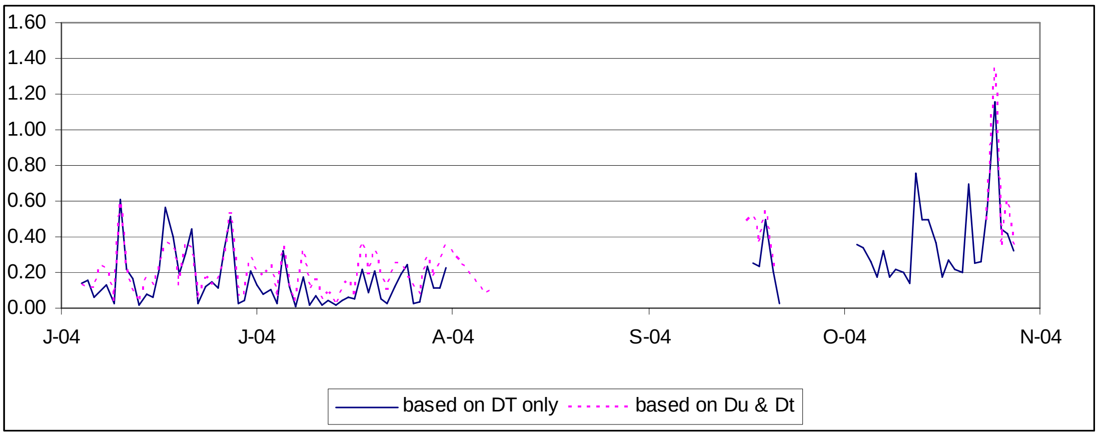

Figure 2- Evaporation from **Sabkht Al Mouh** during 2004

Figure 3 shows the result of the evaporation measurement during the year of 2005 . The minimum value of evaporation was 0.01 mm/day recorded on Aug. 05, while the maximum evaporation was 1.74 mm/day recorded on 5/05. Total evaporation between 12/4/2005 and 30/12/ 2005 was 58.8 mm.

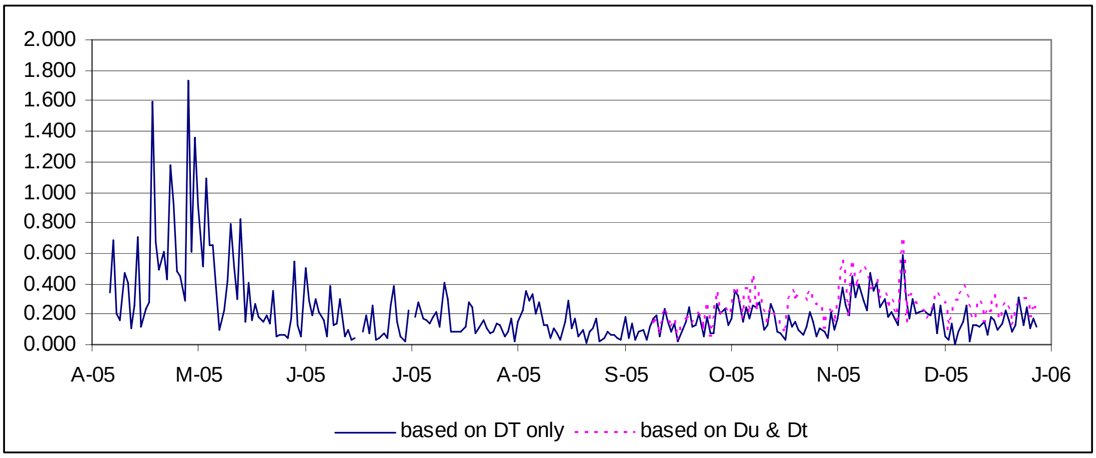

Figure 3- evaporation from **Sabkht Al Mouh** during 2005

As a first conclusion it was found that the evaporation rate is similar to that found by the isotopic study .

E.8.6 Publications

- Jean-Pierre Brunel, Jnad Ihab, Abdallah Droubi, Samar Samaan. 2006. Energy budget an actual evapotranspiration of an arid Oasis ecosystem: Palmyra (Syria). Agricultural water management 84: 213-220
- Jnad, I., J. P. Brunel. A. Droubi. 2005. Comparing eddy covariance and Soil water balance methods for evapotranspiration measurement in Palmyra Oasis. Proceeding of The 7th Gulf Water Conference , Kuwait. (Accepted for publication in Arab Gulf Journal for scientific research)
- Smaan, S. ; M. Al-Sibai, J. P. Brunel. 2005: Estimation of evapotranspiration for Palmyra Oasis using energy budget method, Analytical and experimental study, *Damascus University Journal for Basic Sciences*, 1:21
-

E.9 Report of partner 9 (INRGREF, Tunisia)

OBJECTIVES

Generally, small dams in Tunisia are established in fragile environments and with weak economic activity. The installation of these lakes in Tunisian dorsal mountain region makes it possible to create a new water resource which is suitable to transform the traditional agricultural systems in the rural zones and to ovoid the drift from the land. However at the same time the seasonal and annual irregularity of filling these small reservoirs as their silting up rate, which is sometimes disquieting, pushed the farmers around these lakes to vary their cropping system and agriculture. They grow irrigated vegetables or complementary irrigated crops, rainfed agriculture in the sloppy fields upstream the catchment and fruit-trees with complementary irrigation during the first three years after planting.
For Tunisian partners, IRRIMED project aims to improve management of water resource around small dams. Evapotranspiration measurements at field scale using new technologies like Eddy correlation and scintillometry methods were used to improve crops water requirement evaluation. The combination of these measurements with models was used to explore individual field results on larger scale in the catchment's area.

IRRIMED Program can be regarded as being a continuation of the HYDROMED program whose activities made it possible to release some results which undoubtedly must be confirmed by the next experiments. HYDROMED research results constitute a base for our works in progress and future in IRRIMED.

ACTIVITIES

The evaporation rate calculation methods depend on the availability of the climatic data, the degree of accuracy and the time step required. The measurement is a good way to evaluate evaporation but technical and material difficulties could constitute constraints in some case.

For Tunisian team, represented by INRGREF, the IRRIMED objective is mainly to produce simple and robust methods to assess actual evapotranspiration over large areas and to establish operational tools providing crop water use and supporting efficient management of irrigation under limited water resources conditions.
We have contributed in (1) WP2: Micrometeorological measurements; these measurements consist mainly on adding to an existing Bowen meteorological station an Eddy covariance station based on turbulence analysis, and (2) WP3: Modelling; the objective of WP3 is to evaluate crop evaporation and water balance by models using the WP2 data measurement.

A- Followed methodology

To improve water resource management for irrigation around Kamech small dam the followed demarche consists on three stape of intervention: (1) measurement and modeling at field scale, (2) measurement, spatialisation and modeling at group of field scale and (3) modeling at dam scale.

For the Tunisian program, the contribution on micrometeorological measurement (WP2) leaded by Henk de Bruin from MAQWU (Meteorology and Air Quality of the Wageningen University) consists in using for the first time in Tunisia (1) the Eddy correlation method at field scale and (2) the measurement by scintillometer at transect scale to compute actual evapotranspiration.
The Contribution in WP3 consists on using (1) SVAT Simple model and (2) FAO 56 model to estimate actual evapotranspiration.

B- Description site

For Tunisia, within the project framework, Kamech catchment (capacity of retention of about 142000m^3) was selected as experimental site. The site choice has been fixed by (1) the availability of hydrological and meteorological data since 1994 and (2) the fact that it is a pilot site for the OMERE (Observatoire Méditerranéen de Recherche sur l'Environnement).
Kamech site is located in Cape Bon region (limit of Mediterranean sub-wet and semi-arid superior). It is characterized by a variability of precipitations, a high evaporation rate, a range of soils types and a variety of farming systems and irrigation techniques.

Soils can be classified in: Typical Pélosol (RPF 90), calcareous soil or brown calci soil and calcimagnesic soil (CPCS 75), calcic Kastanozem (FAO), Eutrochreptic rendoll (US Soil Taxonomy). Cultivated area represents 75% of total area (cereals, leguminous plants, irrigated tomato); heavy sloppy fields remain as rangelands for cattle.

However the challenge for choosing this experiment site is to adapt Eddy correlation method in a heterogeneous and small size field (Figure 1) and in a sloppy area.

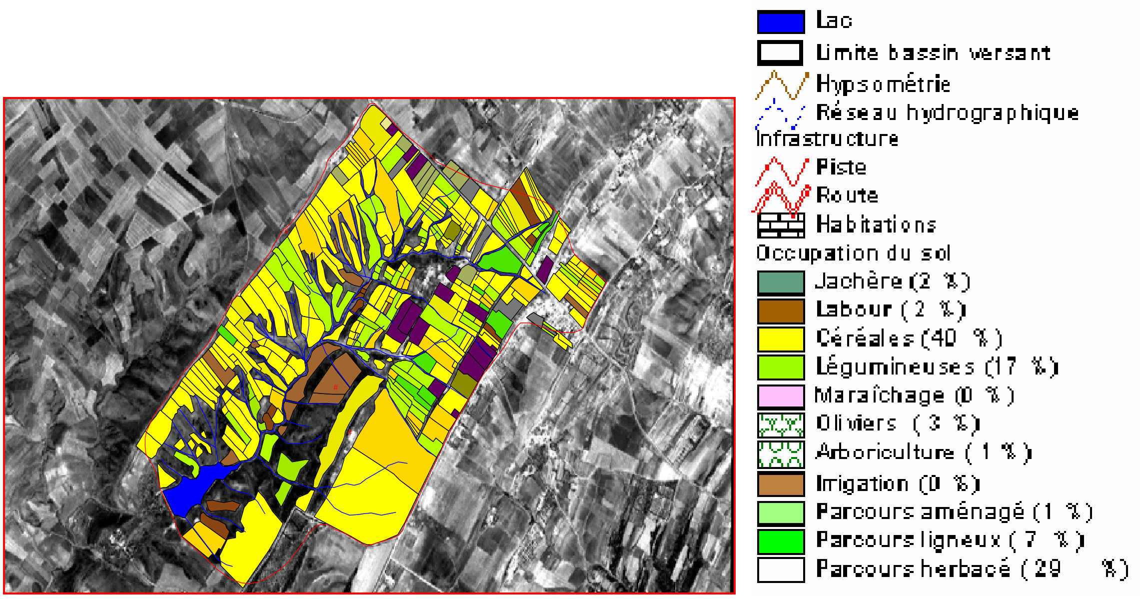

Figure 1: Crops covers in Kamech experiment site.

C- Eddy correlation method: Field scale experiment (WP2)

This micrometeorological method consists in measurement of wind speed fluctuation by sonic anemometer and specific humidity fluctuation by optical hygrometer to calculate sensible heat flux and latent heat flux (ETa actual evapotranspiration).

Eddy correlation station has been installed in Kamech site with help from CESBIO. The location field choice was the first constraint for the experiment field because of the heterogeneity, a sloppy and a small size field (not enough to have an adequate fetch). To characterize dominant wind we have referred to wind speed direction data from Bowen Micrometeorogical Campbell station (Frame work of HYDROMED program). From the results of year 2003 we have concluded that the dominant wind comes from North West. The Eddy correlation station has been located at South East corner of the field and the sonic anemometer and the krypton are in front of the dominant wind.
Eddy correlation system has been installed on field during the period ranging from 2004 to 2006 respectively on: cereals (Durum wheat) that occupies about 45% of total catchments area (03/2004 to 07/2004), bare soil and ploughed soil (06/2004 to 12/2004), Oat used for fodder and largely cultivated in Cap-bon region where is located Kamech catchment because of the presence of bovine and ovine breeding (01/2005 to 06/2005), barley (12/2005 to 03/2006) and faba bean (03/2006 to 05/2006). Chickpea evapotranspiration have been evaluated using Bowen micrometeorological station installed on field in 2004.

The micrometeorological station based on "Eddy covariance" method permits the energy fluxes measurement in order to assess the energy balance. This system consists in measuring sensible heat flux (H), air specific moisture fluctuations, latent Heat flux (Le), heat flux in the ground at 5cm depth (G) and the net radiation at 1.5m height (RN), wind speed and direction at 2m height from the ground, and humidity and temperature gauge at 2m height.
Data acquirement is made using a data logger station "CAMPBELL CR23X". Data storage is done on the data logger station for the half an hour average data and a laptop (Toshiba 100) to store raw data (U, V, W, Ts, rho).
During the experiment field, in addition to Eddy correlation system measurement, agronomic parameters were measured: the LAI (Leaf Areas Index), the plants height and the soil cover and soil water content by the gravimetric method.

D- Modelling: SVAT Simple model and FAO 56 model (WP3)

For Kamech site the objectives of WP3 are (1) to assess reference and actual evapotranspiration and water balance by models, (2) to evaluate the models performances in the specific Tunisian site and (3) to compare data measurement to data simulated by models.
The availability of data from WP2 permits the use of FAO 56 model and SVAT model (Soil Vegetation Atmosphere Transfer).
We used the simple model that is a least complex one. The FAO 56 calculation method has been qualified by Boulet in the first IRRIMED report as a generic and semi-empirical formulation, therefore its applicability for contrasting soil, vegetation, climate and irrigation conditions is questionable. To calculate crop evapotranspiration using FAO 56 method, we used a program data-processing made under Matlab software by G. Boulet and S. Bel Hajj (Workshop on *"crop water modelling tools"* Tunis November 2005).
It is important to note that the FAO 56 calculation method have been qualified by Boulet (IRRIMED first report. IRD contribution to WP3.2004) as a generic and semi-empirical formulation, therefore its applicability for contrasting soil, vegetation, climate and irrigation conditions is questionable.

E- Link with others projects activities

For Tunisian team the IRRIMED activities have progressed at the same time than others collaborations related to evapotranspiration spatialisation in Kamech site.

To measure the energy fluxes at large scale we used the Scintillometer LAS (Procured by INRA Bordeaux). In addition, to complete the data used at field level and in order to spatialize the information across one transect in the watershed, we used a large aperture scintillometers (LAS: it permits to have an average sensible heat fluxes over several kilometres). For this experiment, Tunisian team has benefited of scientific help from LISAH (Laboratoire Interactions sol, Agro système et Hydro système) and INRA Bordeaux that has set up a strong collaboration on the applicability of scintillometry to measure sensible heat.

RESULTS ACHIEVED

A- Micrometeorological Data analysis

A1- Data adjustement

According to the small size of the experimental field crop it was necessary to put the micrometeorological station in one of the corners of the field. The chosen corner for measurements was the Western North one of the field considering the main wind direction.
The data processing consists to remove all recorded data for East and South wind direction and collected data in rainy period during which the anemometer does not record adequate measurements. In addition, in order to correct the effect of the slope, measurements of raw data recorded with an acquisition frequency of 10Hz are converted into file Net-cdf using csi2ncdf-2.2.11 and treated by the software ecpack-2.5.14. An analysis of the energy budget closure has been done.

A2- Energy balance ratio (EBR)

The energy balance ratio EBR:(Rn-G)/(H+Le) was calculated for wheat and the bare soil. As found by Wilson and al in 2003, the regression between LE+H and RN-G is a linear regression. For the filtered half hour data, the regression coefficient is equal to 0.9 (Figure2). The energy balance ratio for the total period was 1.005; this value has been almost found by the same authors for short crop covers. Filtered daily data (Figure3 gave a lower regression coefficient (0.6).

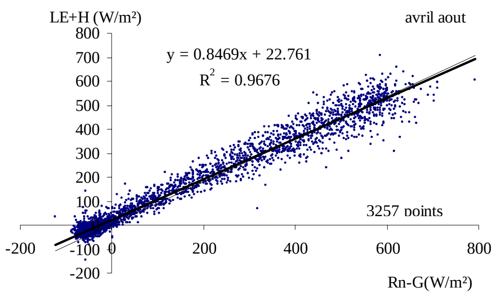

Figure 2: LE+H, Rn-G regression (1/2 hour data)

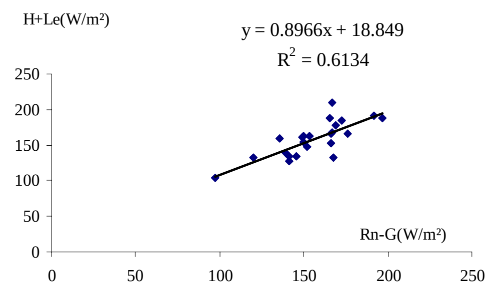

Figure 3: LE+H, Rn-G regression(Daily data)

A3- Gap-filling

With the lack of recorded raw data and data related to south direction conditions, to calculate daily evapotranspiration (main gaol of IRRIMED project), we have filled the gaps by a simple method.

A.3.1- Missing raw data

The collected data are thus not complete for all the period of measurement because of repetitive computer power failure. To fill gaps, we looked for a relation between the heat sensible flux H averaged by the CR23X and the heat sensible flux acquired at 10 hz and corrected with ECpack (Figure 4). We found for wheat in 2004: R^2=0.99, for oat in 2005:0.99 and for faba bean in 2006: 0.93). The slope and topography of these fields is similar for the three years.

These results make possible replacing the missing instantaneous data and correcting directly the half hour data.

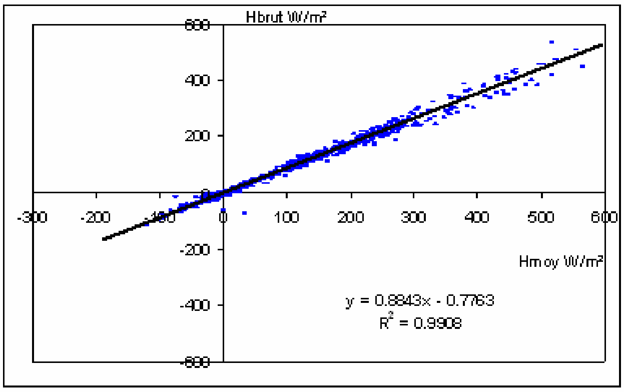

Figure 4: Sensible Heat flux corrected (Hbrut) related to Sensible heat flux recorded by the CR23X(1/2H) (Hmoy). Oat 2005

A.3.2- Missing south direction data

To fill the gaps related to East and Southern wind, we find to good linear relation between net radiation (Rn) and sensible heat flux (H) found for our case study. It is important to note that Greco and Baldocchi, 1996 (Cited by Berbeguier, 2001) have found a second-order polynomial of net radiation. To fill the gaps of sensible heat flux H, we used the relations for short periods along the crop cycle for witch the correlation coefficient is better (R^2= 0.94) than for the entire measurement period (R^2= 0.83) (Figure 5).

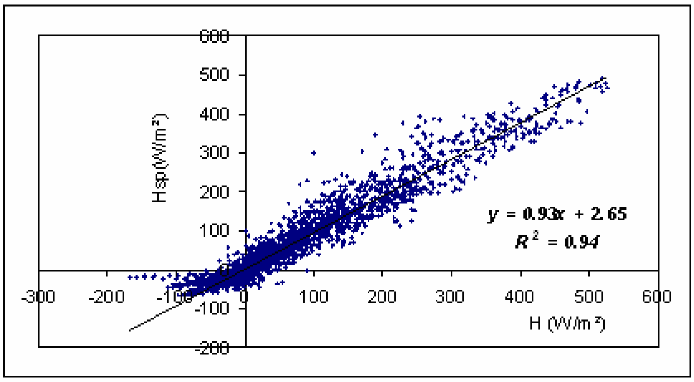

Figure 5: Simulated sensible Heat values (Function related to short periods)

2.3.3- Missing Bowen data to evaluate energy balance

Chickpea evapotranspiration has been evaluated using Bowen micrometeorological station. We collected temperature at two levels, Net radiation, soil heat flux and humidity at 2m height and wind speed and direction. Missing sensible heat data (H) have been calculated by the formula bellow (De Bruin 2004) and missing latent heat (Le) by energy balance.

$$H_{f_i} := \begin{cases} -1.15\cdot 1200\sqrt{\dfrac{grav}{\theta_i + 273.15}}\cdot\Delta\theta_i\cdot\sqrt{|\Delta\theta_i|}\cdot\left[3\cdot\left|(z_b - d)^{\frac{-1}{3}} - (z_h - d)^{\frac{-1}{3}}\right|\right]^{\frac{-3}{2}} & \text{if } \Delta\theta_i < 0 \wedge |\Delta\theta_i| < 5 \\ 0 & \text{otherwise} \end{cases}$$

Data of energy balance components are represented in figures 6 and 7. We represent in the two graphs half hours data of days 28 March and 28 February. In addition to micrometeorological measurement we measured agronomic parameters and soil humidity. Indeed chickpea data are used to calibrate SVAT model.

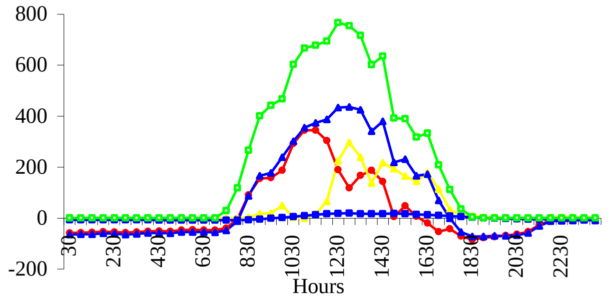

Fig 6: 28 February Bowen data (Kamech. 2004 Chickpeas)

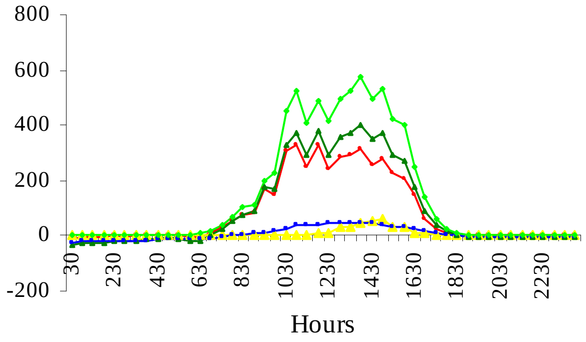

Fig 7: 28 March Bowen data (Kamech. 2004 Chickpeas)

B- Comparing eddy covariance, FAO 56 and SVAT simple methods for evaportanspiration estimation in Kamech site (WP3)

Among the IRRIMED objectives we can note the comparison of methods for evapotranspiration evaluation. Eddy correlation method used at field scale and FAO 56, SVAT simple models and satellite imagery as tools for spatialisation.

In the IRRIMED report of partner 2 (WU, the Netherlands), it was noted that the problem for using the FAO method is due to the fact that “observations of a weather are not done over well-watered grass in most semi-arid regions in addition to a cost maintain, so it would be very useful to derive ET0 form satellite images”. Tunisian team couldn’t be partner in this Work package 4 “Satellite imagery is used as source of spatially distributed information”.

B.1- Comparing ETo and ETa measured and estimated by FAO 56 method

At the end of HYDROMED program, the regional agroclimatic approach (evaluation of ETo and ETa by FAO 56 model using the nearest agroclimatic station to the Kamech site) evaluated crop water needs higher than water consumption during the experimental follow-up for well irrigated tomato and wheat. Actual evapotranspiration evaluation of the same cultures using Bowen method showed also divergences with computed values. Thus which method or equipment is more adapted to evaluate crop water requirements in the context of Kamech site? The answers to this interrogation represent one of the objectives of IRRIMED program.

In the context of IRRIMED, Wheat (2004) and oat (2005) evapotranspiration were evaluated by FAO 56 model and using Eddy correlation method. Obtained data were compared for all the period of measurement. We also determined the Kc curve of oat crop to calculate ETa, we used the approach of the simple crop coefficient which groups in the single coefficient the plant transpiration and the evaporation of ground (Allen and all 1998).
We mention that all missed data have been filled by the methods described on paragraph A3. (Gap- filling). During the measurement period, we found a logic evolution of ETo for daily time scale with a maximum of 7 mm per day and a daily average of 3.3 mm. The maximum ETo registered is relatively high if we consider the experiment period (December to may); this could be explained by the high wind velocities effect. We have found the same result for Tomato crop and wheat in 1999-2000 (Mougou and al. 2006).
The comparison of oat water consumption measured by Eddy covariance system and evaluated by FAO 56 method shows that the two methods gave a very close data (Figures 8, 9). However differences are observed essentially in the end of the period (138-145 Julian days) for which the statistical test emphasizes significant differences (Figure 10)

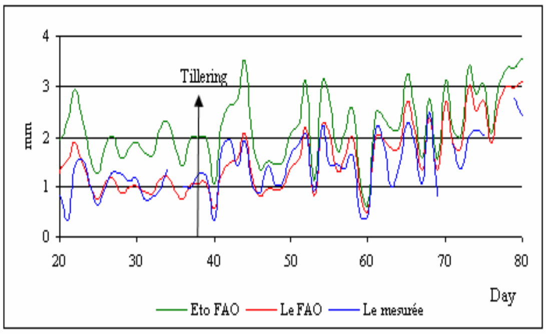

Figure 8: ETo (FAO56), Le oat (FAO 56) and Le oat (Eddy correlation) evolution. 20 to 80 Julian days.

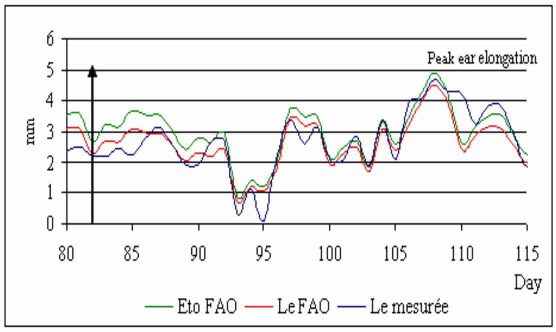

Fig 9: ETo (FAO56), Le oat (FAO 56 Monteith) and Le oat (Eddy correlation) evolution.80 to 115 Julian days

The crop coefficient (ETa/ETo) relating to the oat cultivated period (Figure 11) was evaluated by FAO 56 method and by Eddy correlation measurement. The Kc study constitutes a complementary contribution to understand ETa results.
Figure 9 shows that for the two crop coefficient evaluation methods, the Kc curves have an evolution tendency similar to the oat Kc evolution identified in FAO 56 paper. The three phases of growth, initial phase (Kc in), development phase (Kc mid) and final phase (Kc end) are well identified. However, we remark that at the beginning of the development stage, the measured values of Kc are lower than calculated values and the opposite have been observed at the end of the same stage.

We can note as reported in the FAO 56 chapter related to the condition “where part of the unharvested crop remains suspended above the surface in a dead or senesced condition” witch correspond to our case study after the day 135 (Figure 10), Kc can be set equal to Kc ini; the value for Kc ini can be reduced by about 5% for each 10% of soil surface that is effectively covered by an organic mulch”. This recommendation was not taken into account in the ETa program calculation.

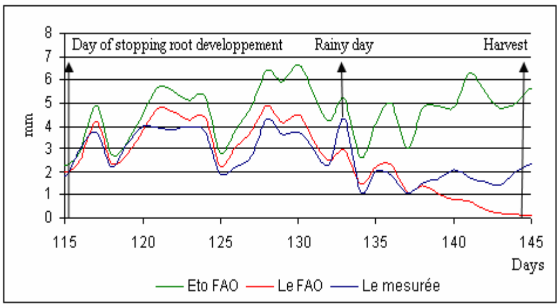

Fig 10: ETo (FAO56), Le oat (FAO 56) and Le oat (Eddy correlation) evolution.115 to 145 Julian days.

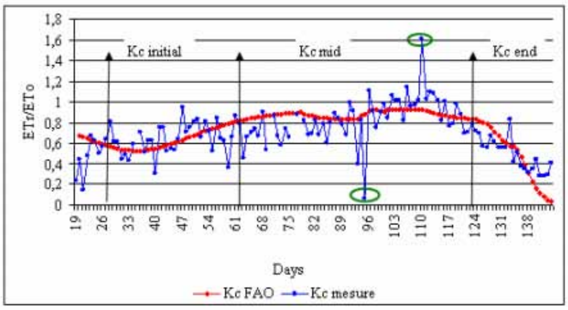

Fig 11: Oat Crop coefficient evolution

B.2- Comparing ETo and ETa measured and simulated by SVAT simple model

A modelling was undertaken with the *SVATsimple* model (Boulet & Al, 2000) that has been developed for sparse semi-arid shorts natural vegetation (such have grass). This model assumes that the rooting system is limited to the shallow subsurface soil, and that the closed vegetation is always to stress conditions because of the low rainfall (more details in IRD contribution to WP3 in 1st IRRIMED rapport).

The first modeling for oat shows that measured and simulated data are well correlated for net radiation (Rn). However, they are less well correlated for sensible heat flux (H) and latent heat flux (Le) (Table 1). Then, for H and Le, simulations should be improved. For the heat flux in the ground (G), the simulation is not good enough, but it can be considered as acceptable regarding to the bibliography (*Olioso et al. 2002*); this could be due to the some unrealistic sensible heat values registered in the beginning and the end of the day. We have to note that the model in not calibrate for our experiments.

Table 1: Statistical coefficients between measured and simulated fluxes (Oat 2005. Days 20 to 164).

	Rn	G	H	Le
Maximum values (W/m^2)	722	216	541	674
R^2	0.97	0.62	0.76	0.97
RMSE (W/m^2)	41.3	36.1	55	49.3

Figure 12 represents the daily simulated (SVAT, FAO) and measured ETa evolution for Oat crop during 2005. The stress that affected the canopy in the days 95 and 125 are well registered as well by measurement than simulated by SVAT simple model.

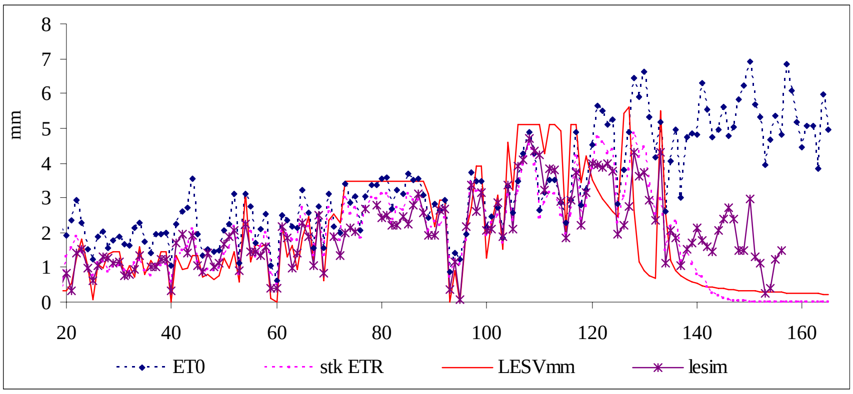

Figure 12: Daily simulated (SVAT, FAO) and measured ETa values (Oat 2005)

ENCOUNTERED PROBLEMS

For Tunisian contribution, contrary to the other teams, the use in Kamech site of the same systems used in the other test sites represented an important constraint to the work progress. The use of Eddy correlation and the Scintillometry systems confronts us with two problems: (1) a delay to acquire the Eddy correlation system and (2) a need of help to install the two systems used for the first time in Tunisia. These two constraints are the main cause of the delay registered on the work progress.

The other encountered constraint is related to the site characteristics. Kamech site is a heterogeneous and sloppy area; this represented both a constraint for the work progress and data analysis and an interest from all a scientific team of IRRIMED. In fact a possibility of Eddy correlation method use in conditions such as Kamech catchment has been a challenge for micro micrometeorological specialists.

TRAINING & EDUCATION

The Tunisian team have benefited from IRRIMED project of the participation on three training workshop:

- The first training workshop organised by ACSAD and held in Palmyra (February 2004) on "***Micrometerological methods for measuring evapotranspiration over crops".***
Have participated in this training from INRGREF, Tunisia: Mougou Raoudha, Nasri Slah and Zitouna Rim.

- The *Second IRRIMED workshop* held in Amman (November 2004) and hosted by Faculty of Agriculture of the University of Jordan on "Satellite images processing for irrigation monitoring".
Have participated in this training from INRGREF, Tunisia: Harmassi Taoufik, and Khalili Amira.

- Third IRRIMED Workshop held in Hammamet Tunisia (November 2005) and hosted by partner 9 (INRGREF) on ***« Crop water modelling tools ».***
Have participated in this training from INRGREF, Tunisia: Harmassi Taoufik, Mansour Mohsen, Slah Nasri and Zitouna Rim.

We have benefited by the borrowing, from Moroccan team, of A Laptop Toshiba 100 and the technical visits of:

- J. Hodges from CESBIO to help in selecting the most appropriate location and to install the Eddy correlation device on the Kamech experimental watershed.

- L. Provot from LISAH (INRA Montpellier) to help for Scintillometry and Eddy system implemantetion.

- M. Irvine from EPHYSE (INRA Bordeaux) to help for Scintillometry implementation.

PUBLICATIONS AND PAPERS

R. Mougou, M. Mansour, J. Vacher, P. Cellier : **La valorisation agricole de l'eau des lacs collinaires : cas du lac collinaire Kamech (Tunisie).** *Sécheresse 2006; 17 (1-2) : 1-6*

- Rim Zitouna : Modélisation de la variabilité du flux de chaleur latente de la parcelle au bassin versant dans un milieu cultivé méditerranéen hétérogène. Supervisors: Prévot L. and Voltz. M. Thesis in progress.

- Zitouna Chebbi R., Mougou. R., Prévot. L. et Voltz. M.: **Mesure de l'évapotranspiration réelle du blé et de l'avoine par la méthode de l'Eddy covariance. Bassin versant Kamech.** Presented in the *« 12ièms Journées sur les acquis de la Recherche Agricole »* Hosted by l'IRESA. 2006, Tunis.

- Zitouna Chebbi R., Mougou. R. **Evaluation de l'évapotranspiration de référence et des besoins en eaux. Bassin versant Kamech (Comparaisons de méthodes).** Presented in the : *Séminaire scientifique de présentation des programmes menés en partenariat entre IRESA et IRD.* 2006, Tunis.

CONCLUSION AND FUTURE PLAN

For Tunisian partners, IRRIMED project that aims to improve tools for evapotranspiration evaluation at field scale using Eddy correlation and FAO 56 model and SVAT models to explore individual field results on larger scale in semi arid area, constituted a real scientific support.

The high interest of IRRIMED project is the complimentarily between all scientists. The project has focused the effort on a continual information and knowledge exchanges.

Concerning the new used techniques we can note that Tunisian team has used for the first time new micrometeorological techniques to measure at local scale and to spatialize evapotranspiration: (1) the Eddy covariance system (technical and scientific support from Morocco and IRD-Toulouse partners), (2) the scintillométre (technical and scientific support from the INRA. Bordeaux and a LISAH (INRA Montpellier) in the frame work of a PHD that will be defended by Rim Zitouna from INRGREF.

The use of Eddy covariance method in Tunisia aroused a great interest from all the specialists in micrometeorological measurements. Indeed this system exists for a long time and its application was extent with the evolution of stocking data systems. However, at present, the use of the method is well known for the flat grounds and not yet known for the sloping grounds such as Kamech. Its application in Kamech site is considered as being a new research and the analysis of results is in progress in close scientific collaboration with all the interested teams.

So for Tunisian team more benefits have arise from IRRIMED project and it could be considered a "success story" even if the analysis are not yet achieved and are in progress.
It is projected to use, in a Tunisian oasis, the IRRIMED project result, mainly related to crop evapotranspiration measurement by Eddy correlation method.

REFERENCES

Berbiguier P., Bonnefond J-Mr. and Mellmann P. 2001: CO_2 and Water vapour flux for 2 years above Euroflux forest site. Agricultural and forest Meteorology, 108, pp: 183-197

(Boulet & Al, 2000)

De Bruin H.A.R.2004: Actual evapotranspiration. Theoretical background and methods of observation. Lectures notes for IRRIMED course in Palmyra. 107 p.

FAO. 1998: Crop evapotranspiration. *Irrigation and drainage paper. 56*. 300p.

Mougou, R, Mansour M, Vacher J. and Cellier P. 2006: La valorisation agricole de l'eau des lacs collinaires : cas du lac collinaire Kamech (Tunisie). *Sécheresse 2006 ; 17 (1-2) : 1-6*

Olioso A., Braud I., Chanzy A., Courault D., Demarty J., Kergoat L., Lewal E., Ottlé C., Prevot L., Zhao W., Calvet J.C., Cayrol P., Jongschaap R., Moulin S., Noilhan J., Wigneron J.P. 2002 (2002) : SVAT modeling over the alpilles-ReSeDA experiment : Comparing SVAT models over wheat fields. *Agronomy 22.* p 651-668.

Wilson K., Goldstein A., Falge E., Aubinet M., Baldocchi D., Berbeguier P., Bernhofer C., Ceulemans R., Dolman H. Field C., Grelle A., Ibrom A., Law BE. Kowalski A., Meyers T., Moncrieff J., Monson R., Oechel W., Tenhunen J., Valentini R., Verma S. *2002: Energy balance closure at FLUXNET sites.* Agricultural and forest meteorology. 113. p 223-245

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We acknowledge all those have been involved in the experiment field: Gouider Ezzeddine, Zrelli Jihène from INRGREF and Ben Younes Mohamed from IRD, Tunis

F ANNEX I - Training Material

For each of the 3 IRRIMED workshops, lectures documents (notes and slideshows) and material for exercises have been compiled into a self contained CD-ROM made available to all project members and any interested visitor of our web site (see page here below)

IRRIMED

an Euro-Mediterranean Research project on
Improved management tools for water-limited irrigation :
Combining ground and satellite information through models

overview | activities | participants | documents | links

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PROJECT WORKSHOPS

As part of the project activities **3 international workshops** have been organised in 3 different countries
The lectures content and exercise material have been edited on CDs

Find here below a brief description of the content of each **workshop CD-ROM**
Simply contact the Coordinator if you would like to **recieve a free copy**

IRRIMED_1
by Drs Henk de Bruin, Benoît Duchemin and Oscar Hartogenis

- Basic Concepts in micrometeorology,
- Operational methods using standard meteorological input data only with emphasis on the FAO operational crop factor approach,
- Advanced methods: Lysimeters, Bowen ratio method, Eddy correlation method
- New methods: Scintillometry, Remote sensing techniques
- Exercises for the lectures (requires MS Excel and MathCad)
- Annexes Some reference papers
- Examples of Eddy Correlation raw measures

IRRIMED_2
by Drs Vincent Simonneaux and Philippe Maisongrande

- Review of basics of remote sensing: -The physical basis of remote sensing - The sensors - The satellite images - Basics of Image processing (exercises)
- Geometric corrections: - Methods - Validation - Mosaicking
- Radiometric corrections: - Principles - Relative correction image – image - Absolute correction using ground measurements
- Thematic interpretation of images: - Principles: quantitative vs qualitative analysis, resolution / object relation, texture, Indices. - Visual interpretation - Classification : methods, choice of classes, classes merging - Validation
- Use of a time series – an example of crop ET estimation using remote sensing

IRRIMED_3
by Dr. Gilles Boulet assisted by Ing. Iskander Belhadj

- Lecture 1: The surface radiation balance
- Lecture 2: The surface energy balance
- Lecture 3: The soil water balance
- Lecture 4: The soil-plant interface

Hands-On sessions on Soil-Vegetation-Atmosphere Transfer (SVAT) models

- Module 1: Preparing input files
- Module 2: The FAO56 method
- Module 3: The SVATsimple model
- Module 4: Optimization

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G Annex II

Improved management tools for water-limited irrigation

Combining ground and satellite information through models

An Euro-Mediterranean research project funded by the European Commission (INCO-MED)

Ministry of Water and Irrigation MWI

and

European Commission (INCO-MED)

IRRIMED End Users Implementation Plan

Document prepared by

Suzan Taha (MWI)

Feras Ziadat (UofJ)

Vincent Simonneaux (IRD-cesbio)

1. Background

Within the INCO-MED Program, the Ministry of Water and Irrigation (MWI) signed an agreement with the European Commission as one partner in a consortium consisting of 9 Euro Mediterranean institutions to implement the IRRIMED[11] Project.

The consortium was built around two European institutions associated with seven partners from four Mediterranean Partner Countries (MPC's), where "MWI" from Jordan and the "Regional Agricultural Development Office of the Haouz (ORMVAH)" from Morocco were participating **as end users**:

1. Institut De Recherche et Développement (IRD) - France
2. Wageningen University (WU) - Netherlands
3. University of Jordan (UOJ) - Jordan
4. National Center For Agriculture Research And Technology Transfer (NCARTT) Jordan
5. Ministry of Water and Irrigation (MWI) - Jordan
6. Faculty of Science Semlalia (FSS) - Morocco
7. Regional Agricultural Development Office of the Haouz (ORMVAH) - Morocco
8. Arab Center For The Studies Of Arid Zones And Dry Lands (ACSAD) - Syria
9. Institut National de Recherche du Génie Rural et des Eaux et Forets (INRGREF) - Tunis

The project, which was launched in April 2003, was aimed at the following:

4. Accurate assessment of actual ETR over selected crop during the growing season, allowing to validate models and to update the crop calendar and crop water requirements
5. Remote sensing of crop extension and evolution during the growing season, to measure the actual acreages of the different crops
6. Refining existing methods for simple ETR estimation, to apply them spatially, deriving ETR maps from satellite data

2. MWI Role in IRRIMED

MWI served both as leader for the "end users" work package, and an end user who has stakes in improvement of the quality of data related to planning for irrigation, and update its information system with validated methods for the estimation of crops water requirements, crop factors, crops calendars and reliable estimates of crops irrigated areas. MWI also served as a local coordinator with its sister organization the Jordan Valley Authority which is responsible for the socio economic development in the Jordan Rift Valley, including the development of water resources, and management and distribution of irrigation water.

As a leader of the end users work package, MWI role was to assist MPC countries; Jordan, Syria, Morocco and Tunis adapt the projects results to suit the end users needs in the respective countries with due consideration to their local conditions.

The **following lists the deliverables related to the end users work package,**

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[11] Improved management tools for water-limited irrigation: combining ground and satellite information through models

- **Definition of the main types of end users to be targeted when discussing operational tool requirements**
- **Internal report to the scientific team on preliminary specifications for the development of the operational tools given Mediterranean Partner Countries specific needs.**
- **End users requirements**
- **Implementation plan**

In order to achieve its objectives, MWI Carried out an End Users Survey **and a** Needs Assessment Study **among** selected end users **in the MPC's, in order to identify the end users issues and requirements for improved irrigation management, given the prevailing irrigation management scheme.**

Two end users meetings were also organised to bring the project scientists with the end users, and help gear the scientists towards meeting the end users requirements, and raise the end users awareness about the project results.

3. Objectives of this report

This report delineates the specific end users requirements which were identified as a result of the interaction between the project scientists and the selected end users in the MPC's. It outlines an implementation plan for the utilization of the project findings by the end users, in order to demonstrate how they could be used to help improve irrigation efficiency and water resources management for irrigation and enable implementation of its results. It should be emphasised that these requirements were originally determined by the selected end users during the first workshop at the beginning of the project. The projects findings, which were designed to answer some of these requirements, were exposed to the end users during the second workshop, toward the end of the project. These were discussed and verified and what is explained in this report is referring to what could be implemented given the end users needs.

The implementation plan includes required data, methodology, cost of deployment of satellite images to serve the respective needs, and recommendation on the type of images needed, the resolution, the frequency of acquisition, and training needs.

4. Selected End Users

Table 1 lists the MPC organisations which were contacted within the framework of IRRIMED project and the organisation type and role.

Table 1: Participating organizations

Country	Organization	Organisation Type and Role
1. Jordan	1.1 Ministry of Water & Irrigation – (MWI)	Governmental; planning of water resources
	1.2 Jordan Valley Authority – (JVA)	Governmental; planning and distribution of irrigation water.
2. Morocco	2.1 ORMVAH	Governmental; planning and distribution of irrigation water
	2.2 Domaine ASSOUFIT - Marrakesh	Private farm, exploiting an agricultural land mostly of fruit trees.
3. Syria	General Commission for Scientific Agricultural Research – (GCSAR)	Governmental; Preparation of irrigation water requirements plans.
4. Tunisia	CRDA De Nabeule	Governmental; planning & distribution of irrigation water.

5. Summary of Issues and Requirements

The following issues were identified as a result of the workshops with the selected end users:

1. Identification of Irrigated Areas & Estimation of Cropped Areas:

The allocation of water by irrigation management institution is done on the basis of the actual area of irrigated crops, and not on the area of farms or potential irrigated area. Thus the knowledge of the actual areas of crops at various times of the year is a basic requirement of all end users. The identification of the main species regarding irrigation (e.g. trees and annual crops, and possibly more details) is also requested. This information about land cover is all the more important as the statistics available from farmers' declarations or ground survey are not considered reliable by the managers.

2. Improved Knowledge of Crops Water Requirements:

Since water allocation is done on equal share basis per hectare (such as in the case of ORMVAH), or based on quotas assigned for main crop categories (Ex: JVA), the knowledge of actual crop development is not a priority for the irrigation distribution, but more for seasonal forecasting (JVA), and planning (MWI). Farmers could also benefit from such information as they need to know as accurately as possible the water needs to minimize the input he usually has to complement. One other use of accurate water requirement assessment offered by satellite image time series at the global level is the estimation of pumping, assuming the difference between observed needs and institutional inputs is coming from ground pumping.

6. Recommended Implementation Plan

6.1 Identification of Irrigation Areas and Estimation of Cropped Areas

6.1.1 End users requirements

As mentioned in Section 5 above, water allocation by the irrigation management institution is done on the basis of the actual area of irrigated crops, and not on the area of farms or potential irrigated area. Thus the knowledge of the **actual irrigation areas at various times of the year** is a basic requirement of all end users.

- ORMWAH - Morocco, which allocates water on the basis of an equal distribution over all areas, regardless of the crop cultivated **requires information on irrigated areas possibly on a tertiary level**. **Improved knowledge of vegetable irrigated areas is also a requirement** which would help in improved planning and network operation.

- This however is not so applicable for planning purposes at Jordan’s MWI, which hosts an extensive database on irrigation areas by crop group, in order to enable estimation of crops water requirements, and assess future irrigation demands using various scenarios including changes in cropping patterns. **MWI requests identification of irrigated areas by crop**. Identification of cropped areas will provide means to protect the exploitation of groundwater resources, which is by far better than remedy measures undertaken to correct the situation

- JVA of Jordan, which allocates irrigation water based on quotas assigned for the following main crop categories; banana, citrus and all other crops (in one group), **requires irrigation areas for the said main species.**

- Since every year irrigated areas are set and fixed by the government, GCSAR of Syria would benefit from the use of image analysis to **monitor actual areas grown by farmers**.

This information about land cover is all the more important as the statistics available from farmers' declarations or ground survey are not considered reliable by the managers.

6.1.2 Methodology

The landcover in many irrigated areas of often complex (small fields (Jordan), many species (Jordan), very similar spectral responses (Jordan Morocco), non synchronous development cycle of crops (Morocco), intra class heterogeneity for trees due to variablez density link to age of the plantation (Morocco). All these problems seriously restrict the applicability of traditional classification methods. It was show in Jordan that only some classes and groups of classes may be correctly discriminated. However this poor species discrimination is not always a big problem as crop water requirements are closely related to vegetation amount which is well related to image information (through indices like the NDVI). Thus, in first approximation it may be possible to obtain satisfactory evapotranspiration assessment without passing through classes identification.

Since last few years, it is possible to obtain satellite high resolution (HR, 10 meters) image times series (every 2 or 3 weeks) to discriminate between species using the temporal evolution of the spectral signature of vegetation. Although in this case also only rough classes are available (annuals, trees, trees on annuals understory, bare soil), the accuracy of such methods may be higher than classical methods based on single images, and useful for Et estimates (Simonneaux et al., 2006).

The investigations indicated that satellite image could be used to identify cropping pattern in an intensively irrigated area. It is important to indicate that the required level of accuracy and purpose of using the results by different users determine the optimum procedure. Two approaches are recommended, visual interpretation and supervised images classification. Visual interpretation is delineating boundaries to enclose group of pixels where the image reflectance is homogeneous. Later these areas are classified based on prior knowledge of the existing crop type on that area. Supervised classification is done by using image-processing software to classify pixels that fall within certain range of digital numbers for different bands into one class. This is followed by giving each class the name of crop based on prior knowledge.

6.1.2.1 Information on irrigated areas (such as on a tertiary level) and improved knowledge of irrigated areas for main species,

Ex: Vegetables (ORMVAH), Citrus (CRDA), and Banana, Citrus and all other crops which include other trees, field crops and vegetables
Visual interpretation produces is recommended for separating crops grouped as trees, annual crops and alfalfa. This is suitable for JVA (operational needs) and for ORMVAH (to differentiate irrigated and non-irrigated areas).

Brief description of the methodology: merged two satellite images: SPOT Pan image (2.5m) and SOPT XI (10m) together. Drape the farm units boundaries over the merged images and train the classifier to differentiate different types of crop groups. Start to assign class for each farm unit based on the image background. Split and/or merge farm units whenever necessary to agree with the image. Visit the field to bring as much as possible of the ground truth points (using GPS). Assess the accuracy of the classification and produce the necessary output (map, chart or report).

6.1.2.2 Irrigated areas by crop

Ex: MWI

Ex: GCSAR where monitoring of planted crops is needed to ensure compliance with government licensing.

Supervised classification to differentiate crops based on their water requirements (alfalfa, wheat, vegetables, orchards, and banana). This classification is more suitable for the MWI use (planning and management tools).

Brief description of the methodology: acquire one SPOT XI (10m resolution) image during a suitable time of the year (probably when intensive land use pattern prevails). Collect as many ground truth from the field. The data collected should include the location (GPS points), type of crop, planting and harvesting dates. Split the total number of field observation into two groups, one as trainer for the classification and one for the verification purposes. Within an image processing software (e.g. ENVI) run the supervised classification algorithm using the field observation to train the classifier. Drape the farm units boundaries over the classified image and assign class for each farm unit. Split and/or merge farm units whenever necessary to agree with the classified image. Assess the accuracy of the classification, using the field observations, and produce the necessary output (map, chart or report).

6.1.3 Implementation requirements

6.1.3.1 Use of Existing database (IRRIMED),

The project managed to collect and compile various types of agricultural- and environment-related information. The project database could be used as starting point to achieve the end users goals and improve the management of water resources. The database includes the following information and GIS layers for the Jordan valley: agro-climatic zones, geology, soil data, topography, administrative boundary, digital elevation model (DEM). In addition, the project managed to collect High-resolution satellite images such as: Panchromatic SPOT image (2.5 m resolution) Multi-spectral SPOT image (10m resolution), in addition to other images (Landsat TM and ASTER images).

6.1.3.2 Satellite images Requirements:

a) **Frequency of Images:** one image every season (4-5 months)

b) **Image Resolution:** for visual classification two images are required, one Panchromatic SPOT image (2.5 m resolution) and one Multi-spectral SPOT image (10m resolution). While for supervised classification only Multi-spectral SPOT image (10m resolution) is needed.

c) Source **of these images:** SPOT Image or local distributors. Special offers might be applicable for regular acquisitions**.**

d) **Expected costs:** these are highly variable, it is advised to visit SPOT image web site to get current prices. Prices in 2007 for one scene, which covers 60 km by 60 km is about 2700 euros

6.1.3.3 Software and hardware Requirements:

a) **Software:** image processing software (e.g. ENVI), GIS software (e.g. ArcView or ARC/GIS).

b) **Hardware:** computer hardware with high speed and storing capacity, GPS, scanners, printers.

6.1.3.4 Resources:

a) **Staff:** trained staff (at least four: two are undertaken office work and two for field visits and data collection). Minimum requirement first university degree. Training will be specified later.

b) **Transportation:** reliable transportation should be available at different time of the season to access the whole area.

c) **Stationary:** regular stationary requirement.

6.1.3.5 Training requirements:

Two type of training is required to recruit the staff to undertake various activities. These are

a) **Training in the form of regular training courses:** general introductory course (principles of GIS and image processing), and more advanced training course in visual interpretation and image classification, which also introduce the remote sensing part within the IRRIMED project.

b) On-job training: continuous training during the course of executing the different activities. This aims at providing continuous advise and guidance for the staff and as sustainable capacity building for training of other staff members.

6.1.4 Expected outputs

Temporal and spatial distribution of cropped areas grouped according to various end users' requirements.

Format: shapefiles, images, charts and/or tabular data.

Possible development of the procedure (building standard algorithms) for easy implementation.

6.2 Improved Knowledge of Crops Water Requirements

6.2.1 End users requirements

Since the use of crop water requirements in allocation is mostly absent, knowledge on the parameters needed for the estimation of Crops Water Requirements was not so relevant for irrigation distribution purposes in the case of ORMVAH. It was more **so for farmers** for water input optimisation, mainly where water provided by the irrigation institution is supplemented with groundwater whenever allocations are insufficient to meet irrigation demands. One other use of accurate water requirement assessment offered by time series at the global level is the estimation of pumping, assuming the difference between observed needs and institutional inputs, is coming from ground pumping.

JVA whose irrigation water allocations are based on quotas assigned for main crop categories (which could be valid for one month or more) could benefit from improved knowledge of crop water requirements to improve its allocation quotas currently compiled from different studies.

A more general request about more reliable methods for water needs assessment, has been pointed out by all end users, as the FAO methods sometimes gives rough results. The following lists the specific requirements by each end user:

- **Validation** of **monthly ETo and Kc throughout the crop development stages,** were such parameters needed in order to enable better estimation of crop evapotranspiration tailored to Saharan **winds (ORMVAH and Assoufit).**

- For seasonal forecasting and planning purposes, both **MWI and JVA** requires improved knowledge of
  - Best Method for the estimation of potential Evapotranspiration (ETo) and validation of penman monteith under local conditions
  - Crop factors during the various stages of crop development (Kc)
  - Crop Calendar for major crops in the Jordan Valley
- GCSAR has established Crop Water Requirements under local conditions and need to validate ETo, Kc and crop calendar.
- CRDA is lacking in meteorological and rainfall stations, but could benefit from validation of best method for estimating ETo.

6.2.2 Methodology:

6.2.2.1 ETo

The FAO method is based on ET0 computed using the Penmann Monteith equation, considered for a standard well watered grass. It is not relevant to question the values of ET0 computed using this equation, because they are virtual values related to the standard grass and are not comparable to any other vegetation. The relevant question would be more investigating the adequacy of alternate formulas which are more simpler and require only the temperature (hargreaves..)

6.2.2.2 Kc

The type fo Kc values needed to improve water budget computing depend on its use, namely the farmer level, the management level, the planning level.

At the farm level, the farmer needs values of the actual Kc in his fields as frequent as possible to update the water requirements and irrigation amounts. In this case the more economical way is to teach the farmer how to estimate theses values based on visual observation, or possibly using hemispherical photographs or radiometers to compute vegetation fraction cover. At the regional level, one may imagine a centralized system that would acquire high resolution satellite images and process them to provide farmers with estimates of Kc of each of their fields, using for example SMS communication. Such a system is currently being tested in the frame of the PLEIADes project funded by the EEC.

At the management level, at any given date in the agricultural season, there is a need for either past water consumption (from beginning to the current date), or future water consumption (from current date to end of cycle). The past consumption may also be obtained on large surface using satellite HR image time series giving for each pixel at regular dates the vegetation development and thus Kc estimates for applyng the FAO method. The future consumption is something much more difficult to obtain as the future development of vegetation depend on many parameters. The two ways of investigation are the modelling approach but this approach comes up this the problem of parameters necessary which are impossible to obtain on large surfaces. The other approach is the statistical approach, based on libraries of observed vegetation development profiles that best fit the actual development and the climate and agronomical hypothesis.

At the planning level, there is a need for better estimates of average Kc profiles of well managed crops in specific areas. Usually this problem is addressed by doing experiments in the field, using Eddy Correlation systems or scintillometry to draw actual Kc curves. The problem of this approach is the poor representation of only some fields, as these experiments are expensive and can't multiplied at the same time. One solution to overcome this problem, would be to use satellite HR image time series to monitor sets of plots of each crop over a region. In this way, a sampling of vegetation development profiles would be obtained for each crop type. Based on some Eddy Correlation field experiments achieve during the same season, it would be possible to get Kc profiles from the NDVI profiles. Among these Kc profiles, the best ones would be considered as representative of the well managed fields, that is to say of locally adjusted Kc profiles.

6.2.2.3 Crop Calendar

As a consequence of above mentioned accuracy problems in crop types identification, the knowledge of the crop calendar in any given area would be best assessed in doing extensive field observations over the whole season. A satellite HR time series acquired during the same year would allow to obtain an development profile of plots observed on the ground. This type of work was already achieved during this project by the Jordanian team in the Jordan valley and gives first draft of the crop calendar. However this was done only during 6 month and not for the whole year. Given the huge diversity of species encountered in this valley, more extensive field work involving larger field staff would allow better observations.

6.2.3 Implementation requirements:

6.2.3.1 Materials Needed

The main material to acquire is Eddy Correlation systems and associated gear (data logger, meteorological sensors, etc.)

6.2.3.2 Existing database (IRRIMED)

Existing databases are useful for research and methods testing (software development), but not for operational purposes. Current have to be acquired on a regular basis for operational use.

6.2.3.3 Satellite images

SPOT, IRS, ASTER, LANDSAT etc. as long as time series programming is possible (currently only SPOT offers that for ordinary customers (non research).

6.2.3.4 Software and Hardware Requirements

Computer and image processing software allow basic processing. A software dedicated to time series processing for Et estimates still has to be developed!

6.2.3.5 Training

- Courses required (general, specific) : advanced image processing (time series)
- On-job training : field instrumentation

6.2.4 Expected outputs

- Temporal and spatial distribution of cropped areas either as individual crops or grouped according to various end users' requirements.
- Temporal and spatial distribution maps of water consumption
- Locally adjusted Kc profiles for main crops for planning purpose.

6.2.5 Possible development of the procedure

- Needs for further research :
- - Better Landcover mapping for irrigation management using satellite times series. Updating procedures for existing maps.
- - Forecast mode for water requirement