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Remote Sensing Applications for Planning Irrigation Management. The Use of SEBAL Methodology for Estimating Crop Evapotranspiration in Cyprus

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Abstract **– Water allocation to crops has always been of great importance in the agricultural process. In this context, and under the current conditions, where Cyprus is facing a severe drought the last five years, the purpose of this study is basically to estimate the needed crop water requirements for supporting irrigation management and monitoring irrigation on a systematic basis for Cyprus using remote sensing techniques. The use of satellite images supported by ground measurements has provided quite accurate results. Intended purpose of this paper is to estimate the Evapotranspiration (ET) of specific crops which is the basis for irrigation scheduling and establish a procedure for monitoring and managing irrigation water over Cyprus, using remotely sensed data from Landsat TM/ ETM+ and a sound methodology used worldwide, the Surface Energy Balance Algorithm for Land (SEBAL).**

Keywords **– evapotranspiration, SEBAL, algorithms, irrigation management**

I. Introduction

There is no bound method to obtain an accurate measure of ETa due to the variability and complexity of climatic factors and biophysical variables involved in the process. Evapotranspiration (ET) estimation is important for hydrologic modeling and irrigation scheduling [1,2,3].
Actual Evapotranspiration ETa is one of the most useful indicators to explain whether the water is used as "intended" or not. ETa variations, both in space and time, and from different land use classes are thought to be highly indicative for the adequacy, reliability and equity in water use; the knowledge of these terms is essential for judicious water resources management. Unfortunately, ETa estimation under actual field conditions is still a very challenging task for scientists and water managers. The complexity associated with the estimation of ET has lead to the development of various methods for estimating this parameter over time [4,5].

Remote sensing based agro-meteorological models are presently most suited for estimating crop water use at both field and regional scales [6]. Numerous ET algorithms have been developed to make use of remote sensing data acquired by sensors on airborne and satellite platforms [7]. This study demonstrates the application of a remote sensing algorithm, the Surface Energy Balance Algorithm for Land (SEBAL)[6,8,9] that is applied employing the necessary modifications and adaptations regarding the crop canopy parameters such as Leaf Area Index and Crop Height. The SEBAL model has been used in several studies [10,11,12,13]. SEBAL was originally applied in Egypt (Bastiaanssen et al., 1998)[8] and then in Turkey (Bastiaanssen 2000)[9] and in Greece[12]. Cyprus is in the crossroad of these countries and it would be very interesting to test its reliability in a country with close but very particular conditions.

In this paper, the evapotranspiration of groundnuts (Arachis hypogaea, L.) in the area of interest located in Cyprus, was determined as the residual of the energy balance equation using the measured net radiation (Rn), the soil heat flux density (G) and the estimated sensible heat flux density (H). The plots cultivated with groundnuts, used in this paper, had quite same canopy characteristics such as age, height, ground cover, leaf area index (LAI), since the only available period for cultivating them is from May to August. Phenological stages of the crop were identified (Table I) in order to follow the phenological cycle and be as accurate as possible.

II. Methodology

Groundnut is a traditional crop cultivated in Cyprus and especially in the Paphos district, since it requires mild meteorological conditions and certain type of soil (well-drained, loose, friable medium textured soils). Its growing period is 90 to 115 days for the sequential, branched varieties and 120 to 140 days for the alternately branched varieties. Groundnut is considered a day-neutral plant and day length is not a critical factor influencing yield. For good yields, a rainfed crop requires about 500 to 700 mm of reliable rainfall over the total growing period [14, 15] (Table I).

TABLE I
MAIN PHENOLOGICAL STAGES OF GROUNDNUTS

	Crop stage	Days
0	Establishment	10-20
1	Vegetative	25-35
2	Flowering[1]	30-40
3	Yield formation (including pod setting and pod filling)	30-35
4	Ripening	10-20

The study area is located in the area of Mandria village, in the vicinity of Paphos International Airport (Figure 1). The selected area is a traditionally agricultural area with a diversity of annual cultivation and is irrigated by Asprokremnos Dam, one of the biggest dams of Cyprus. The area is characterized by a mild climate which provides the opportunity for early production of leafy and annual crops. An advantage of the area of interest is that there is little cloud or cloud free during the year especially in spring and summer time. This fact enables and empowers the use of remote sensing techniques in the area. Another advantage of the area is the existence of a national meteorological station, situated very close (500 meters away from the plots). The area is flat and at the sea level while the surface can be considered homogenous and only annual leafy vegetables are cultivated at the area. Weather during the specific period can be described as hot, humid and cloud-free (more than 80%).

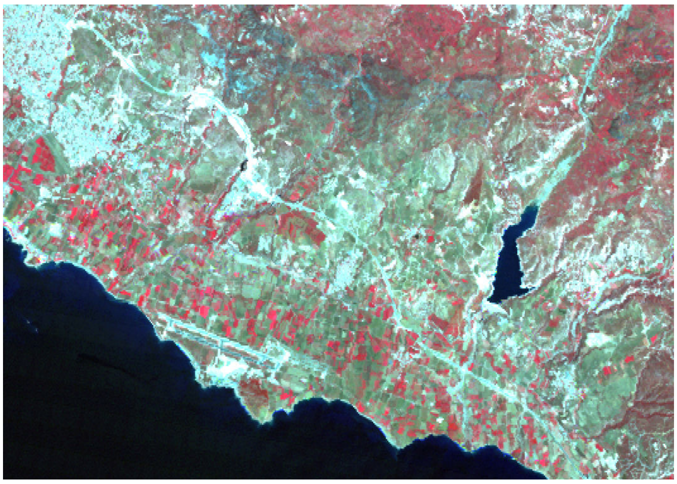

Fig. 1. Landsat-5 satellite image of the area of interest (26 March 2009)

SEBAL model is applied for the first time in Cyprus. In order to be as accurate as possible, all crop related parameters for SEBAL were adapted to the soil, geomorphological and meteorological conditions of the island. Then SEBAL methodology was employed to estimate ETa of groundnuts at the places of interest.

Five Landsat images of the island were used and transformed into ET_a maps. The images were acquired during specific dates in the irrigation period of groundnuts. The irrigation period starts in May and ends in middle of August. The results of the paper are compared to those of Epan method. Then, statistical methods are applied to check if deviation is statistically reasonable.

SEBAL computes a complete radiation and energy balance along with the resistances for momentum, heat and water vapour transport for each pixel [8,9]. The key input data for SEBAL consists of spectral radiance in the visible, near-infrared and thermal infrared part of the spectrum. So, the model can be applied using satellite sensors having a thermal band. Landsat 5 and 7 images were used in this study. In addition to satellite images, the SEBAL model requires weather parameters (wind speed, humidity, solar radiation, air temperature). These meteorological parameters were used as inputs for the algorithm and they were provided from the national meteorological station next to the area of interest. Evaporation was calculated from the instantaneous evaporative fraction, and the daily averaged net radiation, R_{n24}.

The evaporative fraction was computed from the instantaneous surface energy balance at satellite overpass on a pixel-by-pixel basis:

$$\lambda E = R_n - (G_0 + H)$$

where: λE is the latent heat flux (W m^{-2}), R_n is the net radiation (W m^{-2}), G_0 is the soil heat flux (W m^{-2}) and H is the sensible heat flux (W m^{-2}).

The latent heat flux describes the amount of energy consumed to maintain a certain crop evaporation rate. The surface albedo, surface temperature and vegetation index are derived from satellite spectral measurements, and are used together to solve R_n, G_0 and H. The instantaneous latent heat flux, λE, is the calculated residual term of the energy budget, and it is then used to compute the instantaneous evaporative fraction Λ:

$$\Lambda = \frac{\lambda E}{\lambda E + H} = \frac{\lambda E}{R_n - G_0}$$

The instantaneous evaporative fraction Λ expresses the ratio of the actual to the crop evaporative demand when the atmospheric moisture conditions are in equilibrium with the soil moisture conditions. The instantaneous value can be used to calculate the daily value because evaporative fraction tends to be constant during daytime hours, although the H and λE fluxes vary considerably [16, 17]. The difference between the instantaneous evaporative fraction at satellite overpass and the evaporative fraction derived from the 24-hour integrated energy balance is marginal and may be neglected [18, 19]. For time scales of 1 day or longer, G_0 can be ignored and net available energy (R_n - G_0) reduces to net radiation (R_n). At daily timescales, ET_{24} (mm/day) can be computed as:

$$ET_{24} = \frac{86400 \times 10^3}{\lambda \rho_w} \Lambda R_{n24}$$

where: R_{n24} (W m^2) is the 24-h averaged net radiation, λ (J kg^{-1}) is the latent heat of vaporization, and ρ_w (kg m^{-3}) is the density of water.

III. Results

The SEBAL method derives the evaporative fraction from satellite data. Actual evapotranspiration can be easily obtained from the product of the evaporative fraction and the net radiation. The SEBAL remote sensing technique is not restricted to irrigated areas, but can be applied to a broad range of vegetation types. Data requirements are low and restricted to satellite information although some additional ground observations can be used to improve the reliability [20]. SEBAL is essentially a single source model that solves the EB for LE as a residual. Rn and G are calculated based on Ts and reflectance derived values for albedo, vegetation indices, LAI, and surface emissivity. H is estimated using the bulk aerodynamic resistance model and a procedure that assumes a linear relationship between the aerodynamic near surface temperature air temperature difference (*dT*) and *Ts* calculated from extreme pixels. It provides for some bias compensation for errors in *Rn* and *G*. At the pixel with cold condition, *H* is assumed nonexistent (*Hcold* = 0), and at the hot pixel, *LE* is commonly set to zero, which in turn allows *Hhot* = (*Rn* - *G*)*hot*. Then *dTcold* = 0, and *dThot* can be obtained by inverting the bulk aerodynamic resistance equation. The *dT* is expected to compensate for bias in surface temperature estimates due to atmospheric correction. SEBAL has been tested extensively in different parts of the world [8, 21]. It is noticeable that in SEBAL algorithm empirical equations are used to describe parameters that need to be directly measured. Using empirical modeling, direct measurements are avoided. For the application of SEBAL in Cyprus, two empirical equations describing LAI and Crop Height were used. According to Papadavid and Hadjimitsis [22], LAI is best described from Weighted Difference Vegetation Index (WDVI) [23] while crop height from soil-adjusted vegetation index (SAVI) [24] (Figure 2 and 3).

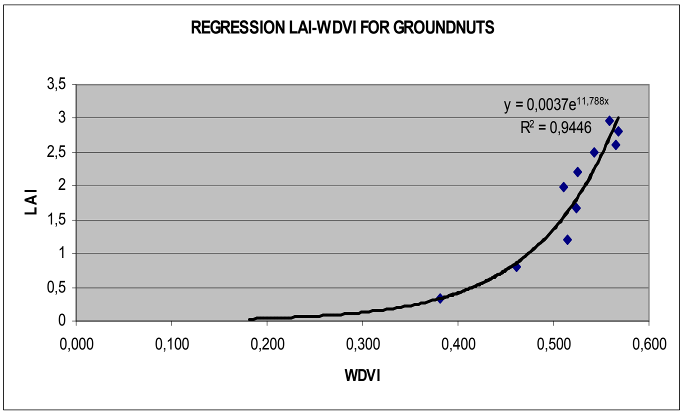

Fig.2. The regression analysis equation describing LAI using WDVI

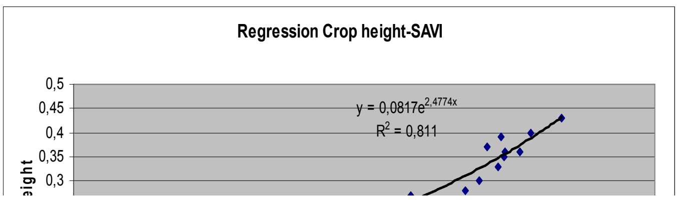

Fig. 3. The regression analysis equation describing crop height using SAVI

The maps of ETa show the daily value of ETa on the date of image acquisition. Figure 4 presents the ETa map (Landsat 5 image) of a groundnut study plot for the 07/07/2009, in mm/day. These maps were employed to infer the value of ETa of groundnuts in all available images at that time from Landsat 5 and Landsat 7 satellites (Table II). The value of ETa refers to the mean value of the four plots of groundnuts at the area of interest which follow the same phenological cycle. Finally ETa values of groundnuts were compared to the Epan method results found in the past [14] (Figure 5).

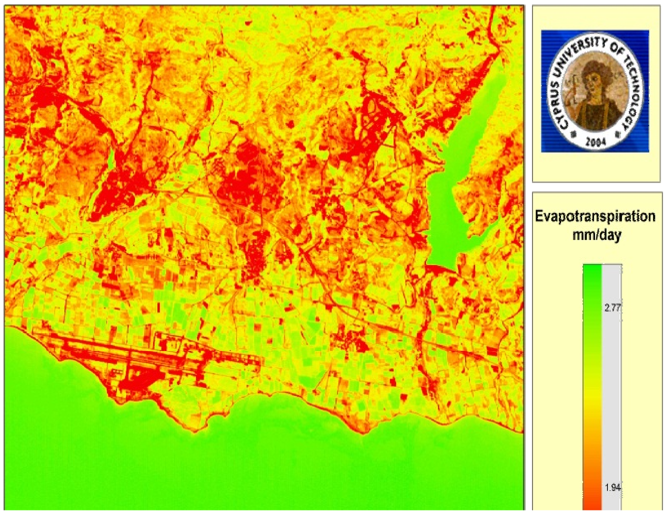

Fig. 4. Example of ET_a map for groundnuts plots in the area of interest

TABLE II

RESULTS OF ETA (MM/DAY) FOR THE DIFFERENT METHODS

Satellite image	SEBAL	Epan
12 July 2008	5,6	5,5
28 July 2008	5,7	5,5
13 August 2008	5,1	4,2
29 August 2008	4,2	4,2
29 June 2009	3,8	2,3
7 July 2009	4,8	5,5
15 July 2009	6,1	5,5
23 July 2009	5,4	5,5
16 August 2009	3,3	4,2

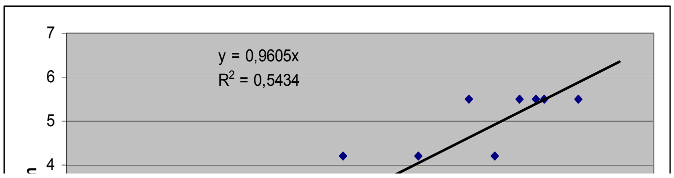

Fig. 5. Correlation between ETc values sourcing from SEBAL algorithm and Epan method

In Table II the results of SEBAL and the results of E pan method are illustrated. These data were found using the Epan method, a direct method, from a research paper of the Agricultural Research Institute of Cyprus [14] and refer to a period of three years (1992-1995). The results found from classic SEBAL and have an average deviation of 0.4 mm/day and are correlated with r^2=0.54 (p=0.05). It is obvious that the regression has a low value of determination coefficient. Of course this is logical since the Cyprus meteorological conditions have changed dramatically the last decade. T-test analysis was employed to test if there is significant difference between SEBAL and Epan method results. The results have indicated that there is no significant statistical difference for the results derived from Epan and SEBAL method. Observed t (0.5) had a lower value than the statistical t (2.365) found from the tables (t obs < t stat.) ensuring that there is no significant difference between the results of the reference based method and the results of SEBAL.

IV. Conclusions

The application of SEBAL algorithm in Cyprus has provided new opportunities in irrigation water management. It is the first time when the specific algorithm is employed for estimating ET in Cyprus. From a technical point of view, SEBAL adapted to Cypriot conditions can be a very useful tool in the hands of water policy makers in order to support decision making on water policy matters.

It was expected that if SEBAL was modified by field measurements to support the empirical and semi-empirical equations used in the algorithm, it would provide more accurate results. Indeed, the algorithm has adopted successfully the few modifications regarding the crop canopy factors and reacted with more accurate results.

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ΚΥΠΡΙΑΚΗ ΔΗΜΟΚΡΑΤΙΑ ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ ΕΥΡΩΠΑΪΚΑ ΤΑΜΕΙΑ

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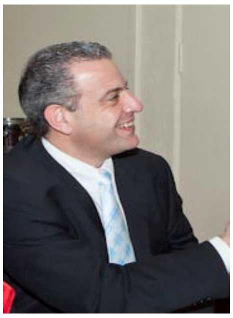

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