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# Satellite-based evapotranspiration of a super-intensive olive orchard: Application of METRIC algorithms

Isabel Pôças [a,b,*], Teresa A. Paço [a], Mário Cunha [b,c], José A. Andrade [d], José Silvestre [a,e], Adélia Sousa [d], Francisco L. Santos [d], Luís S. Pereira [a], Richard G. Allen [f]

[a] CEER Biosystems Engineering, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
[b] Centro de Investigação em Ciências Geo-Espaciais (CICGE), Porto, Portugal
[c] Faculdade de Ciências da Universidade do Porto, Porto, Portugal
[d] ICAAM, Instituto de Ciências Agrárias e Ambientais Mediterrânicas, Universidade de Évora, Évora, Portugal
[e] Instituto Nacional de Investigação Agrária e Veterinária, Dois Portos, Portugal
[f] University of Idaho, Research and Extension Center, Kimberly, Idaho, USA

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METRIC™ is a satellite-based surface energy balance model aimed at estimating and mapping crop evapotranspiration (ET). It has been applied to a large range of vegetation types, mostly annual crops. When applied to anisotropic woody canopies, such as olive orchards, extensions are required to algorithms for estimating the leaf area index (LAI), surface temperature, and momentum roughness length ($Z_{om}$). The computation of the radiometric surface temperature needs to consider a three-source condition, thus differentiating the temperature of the canopy ($T_c$), of the shaded ground surface ($T_{shadow}$), and of the sunlit ground surface ($T_{sunlit}$). The estimation of the $Z_{om}$ for tall and incomplete cover is based upon the LAI and crop height using the Perrier equation. The LAI, $Z_{om}$, and temperature derived from METRIC after these adjustments were tested against field collected data with good results. The application of METRIC to a two year set of Landsat images to estimate ET of a super-intensive olive orchard in Southern Portugal produced good ET estimates that compared well with ground-based ET. The analysis of METRIC performance showed a quantitative improvement of ET estimates when applying the three-source condition for temperature estimation, as well as the $Z_{om}$ computation with the Perrier equation. Results show that METRIC can be used operationally to estimate and mapping ET of super-intensive olive orchards aiming at improving irrigation water use and management.



* *Corresponding author*. CEER Biosystems Engineering, Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisboa, Portugal. Tel.: +351220402160.
E-mail addresses: ipocas@mail.icav.up.pt, isabel.pocas@fc.up.pt (I. Pôças).
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**Symbols and abbreviations**

*Nomenclature*

| | |
|---|---|
| $a$ | adjustment factor for the distribution of leaf area index within the canopy [ ] |
| ALEXI | Atmosphere–Land Exchange Inverse |
| CIMEC | Calibration using Inverse Modelling at Extreme Conditions |
| $D$ | ratio of vegetation height vs. width [ ] |
| DOY | Day of the year [ ] |
| $d$ | zero plane displacement height [m] |
| dT | near surface air temperature difference [K] |
| $E_s$ | soil evaporation [mm d$^{-1}$] |
| $E_{s\ sim}$ | Soil evaporation modelled by SIMDualKc [mm d$^{-1}$] |
| ET | actual evapotranspiration [mm d$^{-1}$] |
| $ET_{ec}$ | evapotranspiration obtained by Eddy Covariance technique [mm d$^{-1}$] |
| $ET_{inst}$ | instantaneous evapotranspiration [mm h$^{-1}$] |
| $ET_{METRIC}$ | evapotranspiration estimated by METRIC [mm d$^{-1}$] |
| $ET_{obs}$ | evapotranspiration derived from field observations [mm d$^{-1}$] |
| $ET_r$ | Alfalfa reference evapotranspiration [mm d$^{-1}$] |
| ETrF | fraction of reference evapotranspiration [ ] |
| $ETrF_{inst}$ | instantaneous fraction of reference evapotranspiration [ ] |
| ETM+ | Enhanced Thematic Mapper Plus |
| $F_{LAI}$ | proportion of leaf area index lying above $h$/2 [ ] |
| $f_{bl}$ | Factor describing the proportion of bottom leafless portion of the tree and not casting a shadow due to the total height of the tree [ ] |
| $f_c$ | fraction of ground covered by vegetation, when viewed from nadir [ ] |
| $f_{nonvisible}$ | Fraction of the canopy that has a shadow under it which is not visible from the satellite [ ] |
| $f_{shadow}$ | Fraction of ground covered by shadow, when viewed from nadir [ ] |
| $f_{shape}$ | factor to adjust for differences in shape between trees and their shadow when viewed from nadir [ ] |
| $f_{stot}$ | fractional area covered by a shadow cast by the crowns [ ] |
| $f_{sunlit}$ | fraction of ground covered by sunlit, when viewed from nadir [ ] |
| $f_w$ | fraction of ground wetted [ ] |
| $G$ | soil heat flux [W m$^{-2}$] |
| $H$ | sensible heat flux [W m$^{-2}$] |
| $h$ | crop height [m] |
| IR | infrared |
| $K$ | Extinction coefficient [ ] |
| $K_c$ | Crop coefficient [ ] |
| $K_{cb}$ | Basal crop coefficient [ ] |
| $K_e$ | Soil evaporation coefficient [ ] |
| $K_{cr}$ | Alfalfa crop coefficient [ ] |
| LAI | Leaf Area Index [m$^2$ m$^{-2}$] |
| METRIC™ | Mapping EvapoTranspiration at high Resolution using Internalised Calibration |
| NDVI | Normalised Difference Vegetation Index [ ] |
| PAR | Photosynthetically Active Radiation |
| $Q_i$ | daily PAR measured at the top of the canopy [μmol m$^{-2}$] |
| $Q_0$ | daily PAR measured below the canopy [μmol m$^{-2}$] |
| $r_{ah1,2}$ | aerodynamic resistance to heat transport between two heights [s m$^{-1}$] |
| $R_n$ | net radiation [W m$^{-2}$] |
| SAVI | Soil Adjusted Vegetation Index [ ] |
| SEBAL | Surface Energy Balance Algorithm for Land |
| $T_c$ | temperature of the canopy [K] |
| $T_{c,METRIC}$ | average temperature estimated with METRIC [K] |
| $T_{c,ground\ data}$ | ground-based temperature [K] |
| $T_{coldpixel}$ | temperature of the cold pixel [K] |
| $T_{hotpixel}$ | temperature of the hot pixel [K] |
| TM | Thematic Mapper |
| $T_s$ | surface temperature [K] |
| TSEB | Two-Source Energy Balance |
| $T_{sf}$ | Plant transpiration [mm d$^{-1}$] |
| $T_{shadow}$ | temperature of the shaded ground surface [K] |
| $T_{sunlit}$ | temperature of the sunlit ground surface [K] |
| $T_{wetbulb}$ | temperature of the wet bulb [K] |
| VI | Vegetation index [ ] |
| $w$ | vegetation width [m] |
| $Z_{om}$ | momentum roughness length [m] |
| $\lambda$ | latent heat of vaporisation [J kg$^{-1}$] |
| $\lambda E$ | latent heat flux [W m$^{-2}$] |
| $\theta$ | sun zenith angle [rad] |

## 1. Introduction

The intensification of irrigated agriculture leads to the need to improve irrigation management and adopt sustainable irrigation practices. These issues are particularly relevant in the Mediterranean regions, where water scarcity problems are rising. In recent years, many olive orchards, which are a major crop in the Mediterranean agricultural systems, have been converted into intensive or super-intensive hedgerow systems, with very high plant density and irrigation (Orgaz, Testi, Villalobos, & Fereres, 2006; Testi, Villalobos, & Orgaz, 2004; Testi, Villalobos, Orgaz, & Fereres, 2006). Therefore, the accurate estimation of crop water requirements, i.e., crop evapotranspiration (ET), and its spatio-temporal variability at field level is an increasingly important issue for optimising water management.

In recent decades, remote sensing-based techniques have been used for irrigation water management (e.g., Calera, Jochum, García, Rodríguez, & Fuster, 2005; D'Urso et al., 2010). The synoptic and repetitive coverage of Earth Observation data with high spatial resolution makes this type of data interesting for monitoring and quantifying the spatial and temporal variation of ET. The most widely used remote