Estimating Radiation Interception Using High Resolution Multispectral Imagery In Open-Tree Orchards

M.L. Guillén-Climent[1], P.J. Zarco-Tejada[1], J.A.J. Berni[1], F.J. Villalobos[1, 2]

[1] Instituto de Agricultura Sostenible, IAS-CSIC, Córdoba, Spain
[2] Dpto. de Agronomía, Universidad de Córdoba, Spain

Introduction

Solar radiation is the main source of energy for physiological processes conducted by plants. It drives fundamental plant and biophysical processes, such as photosynthesis, stomatal conductance, transpiration, leaf temperature, respiration and other secondary plant processes. The supply of radiation is a limiting factor to potential production, determined by the incident radiation condition as well as by the optical and architectural properties of the stand (Ross, 1981).

The objective of this work is the development of methodologies for remote measurement of radiation absorption in photosynthetically active radiation (PAR) and near infrared (NIR) bands in heterogeneous canopies. The study was conducted using high resolution multispectral imagery acquired in diurnal flight campaigns over peach and orange orchards. A leaf-canopy radiative transfer model linked to a radiation interception model was validated against field-measured radiation interception data acquired with a ceptometer over the course of the day. The 3D radiative transfer modelling approach enabled accounting for orchard architecture, planting grid, crown dimensions and background effects on the Normalized Difference Vegetation Index (NDVI) used as an indicator for canopy radiation interception. Estimates for radiation interception using the modelling approach yielded errors below 13% RMSE.

Methodology

Study sites

The ground truth datasets and airborne images were acquired in two commercial peach and orange orchards located in Cordoba (37º 48'N, 4º 48'W) and Seville (37º 20', 5º50'W), respectively. The peach orchard was planted in 5 x 3 m pattern and the orange trees in 7 x 3 m pattern.

Field data collection

A ceptometer (SunScan Canopy Analysis System, Delta-T Devices Ltd, Cambridge, UK) was used for the ground truth data of intercepted radiation. The measurements were taken beneath the four central trees of the orchard. The multispectral sensor used in this study was a 6-band multispectral camera (MCA-6, Tetracam, Inc.,California,USA), with centre wavelengths at 490, 550, 670, 700, 750, and 800 nm. Bands centered at 670 and 800 nm were used for computing the *Normalized Difference Vegetation Index* (NDVI).

Simulations with a leaf-canopy radiative transfer and radiation interception models

The leaf-canopy radiative transfer model, FLIGHT 5.5 (North, 1996) linked to a radiation interception model (Mariscal et al., 2000) were validated against field-measured radiation interception data acquired with the ceptometer over the course of the day. The FLIGHT 5.5 3D canopy model enabled us to simulate the effects of different input parameters on NDVI, such as the orchard architecture, planting grid and background effects.

Results

A first approximation to estimate intercepted radiation by using remote sensing was conducted assessing the relationship between vegetation indices calculated from the airborne imagery (NDVI) and field-measured intercepted radiation measured with the ceptometer (Fig.1). The aggregated image reflectance from the four central trees of the orchard, including soil and shadows, was used to compute NDVI. The diurnal variation of NDVI over the course of the day (Figure 1) was driven by soil and shadows variation as function of the sun geometries. To evaluate the influence of these parameters in the vegetation index, the 3D canopy model, FLIGHT5.5, was used. An example is illustrated in Fig 2, showing the changes in canopy NDVI as a function of the planting pattern. The canopy model shows the sensitivity of NDVI to planting grids and leaf area densities, therefore suggesting the need for understanding NDVI as a function of canopy structure in open canopies. These results suggest the need for assessing NDVI as function of ground cover, leaf area index and soil background. The relationship between NDVI and intercepted radiation in open canopies conducted linking the canopy reflectance model with the interception model developed by Mariscal et al (2000) yielded estimates with errors below 13% (Figure 3). These results were obtained relating modelled NDVI with radiation interception as function of canopy and structural parameters, viewing geometry and leaf optical properties required as inputs for the two models.

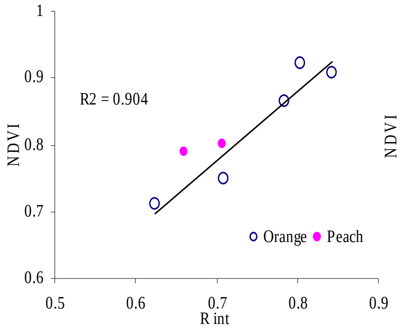

Fig. 1 Relationship between NDVI and fraction of radiation intercepted at different times of the day.

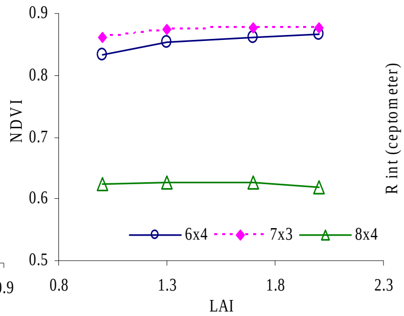

Fig. 2 Effects of different planting patterns on NDVI.

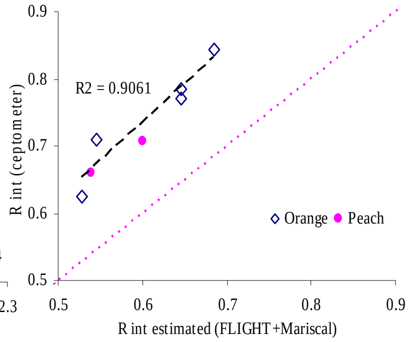

Fig. 3 Relationship between measured and simulated intercepted radiation.

Conclusions

High-resolution airborne NDVI acquired diurnally is a potential indicator of intercepted radiation in heterogeneous canopies. However, simulation assessments conducted on NDVI as a function of canopy architecture, soil background and sun angle demonstrate that NDVI is highly affected by these parameters. A methodology based in 3D models enabled the simulation of canopy reflectance linked to radiation interception simulations, assessing the effects of leaf, canopy, background and sun geometry inputs on NDVI. Intercepted radiation estimates through the linked models validated against field measurements yielded a relative RMSE of 13% and r^2=0.906. The goal is to adapt and validate this linked model approach to other open-tree orchards to map radiation interception at the orchard scale.

Acknowledgements

This work was funded by grant AGR-595 of Consejería de Innovación, Ciencia y Empresa (Junta de Andalucía, Spain)

References

Marical M.J. et al. 2000. Modelling and measurement of radiation interception by olive canopies. Agricultural and Forest Meteorology, 100:183-197.

North P.R.J. 1996. Three dimensional forest light interaction model using Montecarlo method. IEEE Transactions on Geoscience and Remote Sensing, 34(5):946-956.

Ross J. 1981. The Radiation Regime and Architecture of Plant Stands. Dr W. Junk Publishers, The Hague, The Netherlands, p. 391