

Determination of surface resistance to evapotranspiration by remote sensing parameters in the semi-arid region of Brazil for land-use change analyses

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Abstract Field energy balances from irrigated crops (vineyards and mango orchard) and natural vegetation (*caatinga*) together with a net of agro-meteorological stations were used to develop a model for the surface resistance (r_s) to evapotranspiration at the basin scale in the semi-arid region of Brazil for land-use change analyses. It was done to make a historical picture at the municipal-district level of vegetation replacement in Pernambuco (PE) and Bahia (BA), Brazil. Although Petrolina, PE and Juazeiro, BA presented the biggest irrigated areas, the increments throughout the years (2002–2006) were smaller (213 and 171%) than those for Santa Maria, PE (275%) and for Lagoa Grande da Boa Vista, PE (260%).

Key words energy balance; satellite measurements; water resources

INTRODUCTION

The intensification of agriculture in the Low-Middle São Francisco River basin, Brazil, with mainly fruit crops, has caused large land-use changes, with the replacement of the natural vegetation (*caatinga*) by large irrigated areas. Water scarcity in some areas and periods of the year has been a problem, and the drainage of irrigated agriculture may affect the water quality. To avoid both water scarcity and water excess, one must have efficient tools to quantify the intensity of these processes.

A model to obtain the surface resistance (r_s) based on the Penman-Monteith equation was developed and applied to infer the soil moisture conditions for a simplified vegetation classification. Landsat satellite images of the study region were layered with the shapes of the main fruit growing regions in the Pernambuco (Petrolina, Lagoa Grande and Santa Maria da Boa Vista) and Bahia (Juazeiro and Casa Nova) states, and with a net of seven agro-meteorological stations to identify the main direction of the rapid land-use change, highlighting the best possibility for the irrigation expansion and to subsidize the agricultural managers in the semi-arid region of Brazil.

MATERIALS AND METHODS

Data from four energy balance experiments, involving irrigated crops and natural vegetation (Teixeira *et al.*, 2008), were used to determine r_s in field conditions by inverting the Penman-Monteith equation (Allen *et al.*, 1998), which were further related to the surface parameters obtained from 10 Landsat images for the years 2001–2007 (Teixeira *et al.*, 2009). The equation below was then applied for classifying irrigated crops and natural vegetation at municipality level.

$$r_s = \exp \left[a \left(\frac{T_0}{\alpha_0} \right) \left([1 - NDVI] \right) + b \right] \quad (1)$$

where α_0 and T_0 are the surface albedo and surface temperature after corrections applying regression equations between satellite and field measurements have been made (Teixeira *et al.*, 2009), and $NDVI$ is the Normalized Difference Vegetation Index. Figure 1 shows the good correlation between the field and remote sensing parameters.

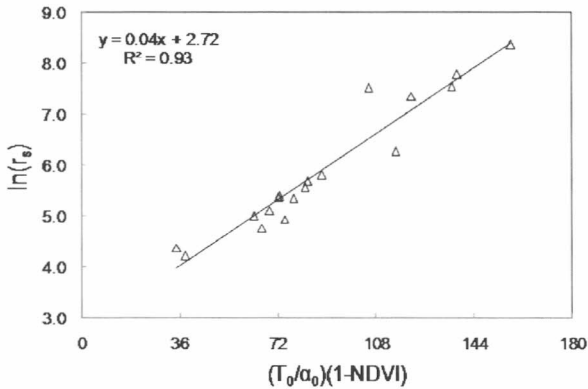


Fig. 1 Relation for the evapotranspiration resistances and remote sensing parameters. Surface resistance – r_s ; T_0 – surface temperature; α_0 – surface albedo; $NDVI$ – Normalized Difference Vegetation Index.

RESULTS AND DISCUSSION

Figure 2 shows the satellite overpass images of r_s representative for the dry (Fig. 2(a)) and for the rainy (Fig. 2(b)) periods in the semi-arid region comprised of the net of agro-meteorological stations.

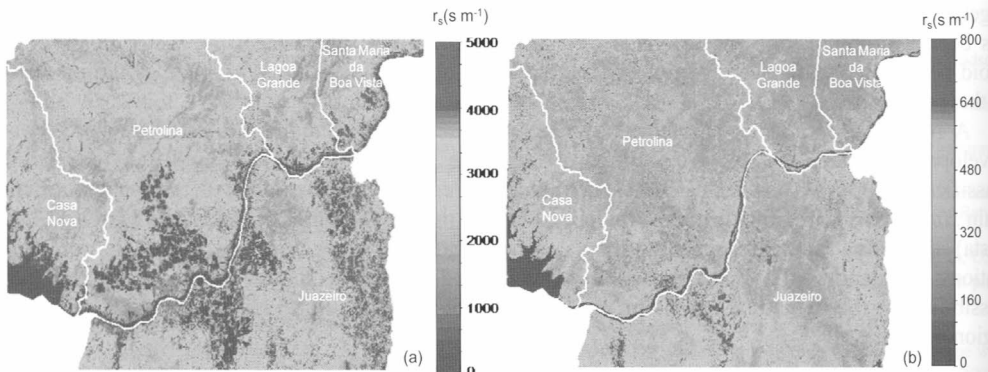


Fig. 2 Images of the satellite overpass surface resistance for the region comprised of the net of agro-meteorological stations in the Low-Middle São Francisco River basin. (a) October 2005. (b) January 2007.

In Figure 2, during the first period, the irrigated crops with much lower values than *caatinga* are strongly highlighted. In general, the *caatinga* shows r_s values higher than 800 s m^{-1} during the dry period of the year (Fig. 2(a)). During the wet period there is more homogeneity over the whole area, and both irrigated and not irrigated vegetated areas present values of less than 800 s m^{-1} . The relation of r_s with soil moisture shows the suitability for estimating this last important water variable in semi-arid regions which involve a mixture of ecosystems. The maximum values are for *caatinga* (average of 1937 s m^{-1}). Wine grapes and mango orchards present similar values around 130 s m^{-1} , while table grapes present the lowest values, averaging 74 s m^{-1} (Teixeira *et al.*, 2008).

Considering that the rapid land-use change by the replacement of natural vegetation with irrigated crops can cause environmental problems, it becomes very important to make a historical picture at the growing regions level about this replacement. Figure 3 presents the evolution of the irrigated areas during the period 2002–2006 for the growing regions involved in the net of agro-

meteorological stations, by using the classified satellite data. The total irrigated areas were calculated by summing the number of pixels with r_s values lower than 800 s m^{-1} and multiplying this number by the area of each pixel. Images of 2001 and 2003 were interpolated to give the situation for 2002, and the 2006 image gave the situation for that year.

Although Petrolina, PE and Juazeiro, BA, present the biggest irrigated areas, the increments throughout the years (2002–2006) are smaller (213% and 171%) than those for Santa Maria, PE, (275%) and for Lagoa Grande, PE (260%). The municipality of Casa Nova, BA, showed an intermediate value of 198%, being the best option for irrigation expansion.

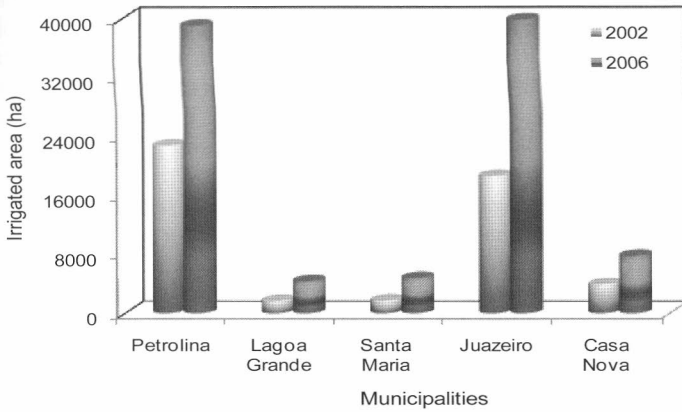


Fig. 3 Evolution of irrigated growing areas comprised of the net of agro-meteorological stations, in the Low-Middle São Francisco River basin.

The most important commercially irrigated crops in the semi-arid region of Brazil are vineyards and mango orchards, being the crops primarily responsible for the rapid land-use change, growing mainly in Petrolina, PE and Juazeiro, BA. Figure 4(a) shows the evolution of the areas with the first crop, while Fig. 4(b) depicts the increment for the second crop in the growing regions of Petrolina, PE, and Juazeiro, BA, based on the data from Brazilian Geographical and Statistical Institute (IBGE).

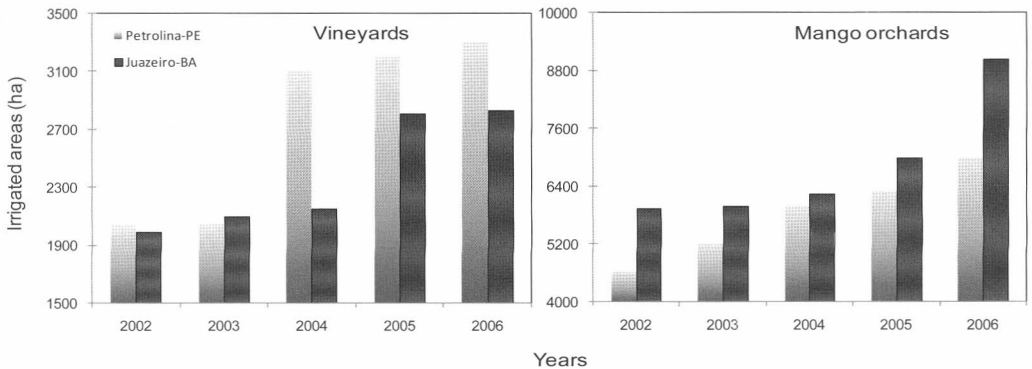


Fig. 4 Evolution of cultivated areas with vineyards and mango orchards for the centres of development Petrolina, PE/Juazeiro, BA in the Low-Middle São Francisco River basin.

In the case of Petrolina, PE, the larger increase is for vineyards, while in Juazeiro, BA, the biggest area is for mango orchards. The highest increment for the first crop was verified between

2003 and 2004 in Petrolina, PE, when the cultivated area increased by 151%. In the case of mango orchards, the most significant period was from 2005–2006 in Juazeiro, BA (129%). The agricultural water usage in both growing regions is highly productive. The cities have increased in terms of exports, and are good examples of converting marginal savannah land into booming rural developments; however, planning the expansion of irrigated areas requires irrigation management and full attention to tools for analysis of the regional ET.

CONCLUSIONS

Field radiation and energy balances in natural vegetation and irrigated crops, together with agrometeorological stations and Landsat images, were used to develop a model to quantify the surface resistance to evapotranspiration to infer the soil moisture conditions for a simplified vegetation classification. The maximum values of surface resistance were for natural vegetation—*caatinga* (average of 1937 s m^{-1}). Wine grapes and mango orchards presented similar values of around 130 s m^{-1} , while table grapes presented the lowest ones, averaging 74 s m^{-1} . Petrolina, PE, and Juazeiro, BA, were highlighted as having the biggest irrigated areas.

The most important commercially irrigated crops in the semi-arid region of Brazil are vineyards and mango orchards, being primarily the crops responsible for the rapid land-use change, and growing mainly in Petrolina, PE, and Juazeiro, BA. In the case of Petrolina, PE, the larger increase is for vineyards, while in Juazeiro, BA, the biggest area is for mango orchards. The highest increment for the first crop was verified between 2003 and 2004 in Petrolina, PE, when the cultivated area increased by 151%. In the case of mango orchards, the most significant period of increase was from 2005 to 2006 in Juazeiro, BA (129%).

The tools tested and presented here can be operationally tested and implemented to monitor the increase of irrigated agriculture, so assisting ways to avoid environmental damage in hydrological basins with increasing land use change.

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