SPATIAL DYNAMICS OF REMOTE SENSING VARIABLES IN IRRIGATE ROBUSTA COFFEE

Luan Peroni Venancio[1], Roberto Filgueiras[2], Ivo Zution Gonçalves[3], Robson Argolo do Santos[4], Jannayton Everton Oliveira Santos[5]

ABSTRACT: The state of Espírito Santo is a successful reference in the production of robusta coffee (*Coffea canephora*), being responsible for approximately 20% of all world production and 80% of Brazilian production. This study aimed to analyses the spatial dynamics of remote sensing variables in irrigated-areas of robusta coffee through microjet and sprinkler irrigation systems as an indicators of irrigation management variability and coffee development. Then, actual evapotranspiration (ETa), land surface temperature (LST), normalized difference vegetation index (NDVI) and, surface albedo (α) products from EEFlux (Google Earth Engine Evapotranspiration Flux), were used. The variability was accessed using maps and descriptive statistical. Microjet-irrigated areas have higher LST and lower NDVI and albedo values than sprinkler-irrigated areas, on the other hand, ETa has being very similar. EEFlux products can be accessed by anyone and, it's an important indicators of irrigation management spatial variability and coffee development at farm-scale.
KEYWORDS: *Coffea canephora*, evapotranspiration, NDVI, surface temperature, albedo.

DINÂMICA ESPACIAL DE VARIÁVEIS DE SENSORIAMENTO REMOTO EM CAFÉ ROBUSTA IRRIGADO

RESUMO: O estado do Espírito Santo é referência de sucesso na produção de café robusta (*Coffea canephora*), sendo responsável por aproximadamente 20% de toda a produção mundial e 80% da produção brasileira. O objetivo deste trabalho foi analisar a dinâmica espacial de variáveis de sensoriamento remoto em áreas irrigadas de café robusta pelos

[1] Prof. Doutor, Depto de Engenharia Agrícola, UFV, Viçosa, MG.
[2] Doutorando, Depto de Engenharia Agrícola, UFV, Campus Universitário, CEP 36570-900, Viçosa, MG. Fone (38) 99973-9755. e-mail: roberto.f.filgueiras@ufv.br
[3] Pós-Doutorando, Daugherty Water for Food Global Institute, University of Nebraska, Nebraska Innovation Campus, 2021 Transformation Dr. Ste 3220, ZIPCODE: 68588, Lincoln, NE, USA.
[4] Doutorando, Depto de Engenharia Agrícola, UFV, Viçosa, MG.
[5] Doutorando, Depto de Engenharia Agrícola, UFV, Viçosa, MG.

sistemas de microjet e aspersão, como indicadores da variabilidade do manejo da irrigação e do desenvolvimento cafeeiro. Para tanto, evapotranspiração real (ETa), temperatura da superfície terrestre (LST), índice de vegetação por diferença normalizada (NDVI) e albedo da superfície (α), produtos do EEFlux (Google Earth Engine Evapotranspiration Flux), foram utilizados. A variabilidade foi acessada por meio de mapas e estatística descritiva. As áreas irrigadas por microjet apresentam maiores valores de LST e menores de NDVI e albedo do que as áreas irrigadas por aspersão, por outro lado, a ETa foi muito similar. Os produtos da EEFlux podem ser acessados por qualquer pessoa e, provaram ser indicadores importantes da variabilidade espacial do gerenciamento da irrigação e do desenvolvimento do café no nível da fazenda.

PALAVRAS-CHAVE: *Coffea canephora*, evapotranspiração, NDVI, temperatura da superfície, albedo.

INTRODUCTION

Robusta coffee (*Coffea canephora*) is the most important crop of the state of Espírito Santo, Brazil and, it's cultivated predominantly in the northern region of the State where most plantations coffee crops are irrigated. The main irrigation methods used for coffee are the sprinkler (conventional fixed and center pivots) and microirrigation (drip, microjet and micro-sprinklers). Although irrigation is a consolidated practical in the region, it's rare the irrigator that have an irrigation management system, even simple, in order to optimize the use of water and electricity.

The lack of an irrigation management system in turn, makes the definition of the correct irrigation depth most complex, increasing the chances of applying excess or deficit water, which will lead to spatial variability of development and on the crop productivity. The study of spatial variability in cropping system is very important in order to improve management options and improve profitability of the production system (Bernardi et al., 2014). Remote sensing variables maps, such as actual evapotranspiration (ETa), Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and albedo (α) can be an efficient tool for detecting variations in plant development caused by an inefficient irrigation management, supporting farmers to identify crop variability more easily.

These variables can be accessed globally using EEFlux (Earth Engine Evapotranspiration Flux) and it is a version of METRIC (Mapping Evapotranspiration at high

Resolution with Internalized Calibration) that operates on the Google Earth Engine (GEE) system (Allen et al., 2015; Foolad et al., 2018). EEFlux uses Landsat imagery archives stored on GEE, a cloud-based platform. A web-based interface provides to the users the ability to request several remote sensing variables maps for any Landsat 5, 7 or 8 scene quickly (Foolad et al., 2018).

EEFlux products can be considered "ready-to-use remote sensing product". Thus, this easiness has been motivating the scientific community to use these products instead to performs a laborious imaging processing to generate similar products. Examples can been seen in study of Akbariyeh et al. (2019), Bhattarai & Liu (2019) and Valayamkunnath et al. (2018). Thus, the aim of this study was to analyses the spatial dynamics of remote sensing variables in irrigated robusta coffee using microjet and sprinkler irrigation systems as an indicators of irrigation management variability and coffee development.

MATERIAL E METHODS

The study areas belong to a commercial farm, located at the municipality of Vila Valério in the northwest region of Espírito Santo State, Brazil. The areas is located in the rectangle bounded by the coordinate pairs: 19°04'27"S-40°21'00"W and 19°04'59"S-40°20'44"W, with an average altitude of 70 m above the sea level (Figure 1). According to Köppen’s climatic classification (Alvares et al., 2013), the climate of region is tropical climate (Aw), with rainy season in summer and dry winter, with an annual normal precipitation in the region of 1,267.2 mm (INMET, 2018), concentrated in the rainy season (October to April).

It was used in this study the following remote sensing products: (i) actual evapotranspiration (ETa, mm day^{-1}), Land Surface Temperature (LST, °C), Normalized Difference Vegetation Index (NDVI) and, surface albedo (α). These products are available globally at EEFlux (Google Earth Engine Evapotranspiration Flux - https://eeflux-evel1.appspot.com/) which operates on the Google Earth Engine system (Allen et al., 2015; Foolad et al., 2018). It was used only a cloud-free image (May 24, 2019) belong to Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) sensors, aboard Landsat 8. order to compare the data of ETa, LST, and NDVI referring to the microjet and sprinkler irrigated areas were used the following descriptive statistics: minimum (Min), maximum (Max), range, mean and standard deviation (SD).

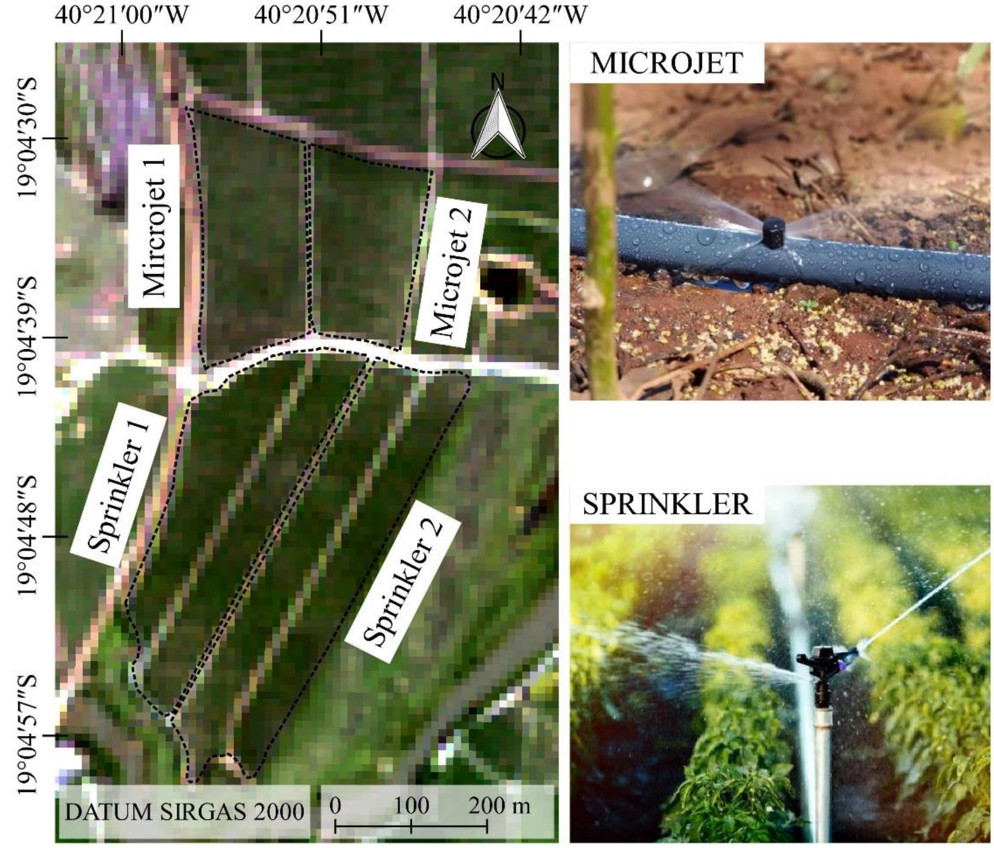

Figure 1. Study areas delimitation and examples of the irrigation systems.

RESULTS AND DISCUSSION

Figure 2 shows maps of LST, ETa, NDVI and α for irrigate robusta coffee areas using sprinkler and microjet irrigation systems. LST are higher in the areas irrigated by microjet because just a small area of the soil surface is irrigated. On the other hand, sprinkler system apply water on the fully areas (Figure 2A). In sprinkler area can be identified clearly two temperature zone, as consequence of the irrigation by sectors rather than the whole area at once. Probably, the southern part of both sprinklers areas, 1 and 2, were irrigated to the less time than north part. In respect to the ETa data, similar values were verified for both systems (Figure 2B). Differently of these findings, a simulation study of Venancio et al. (2016) in Linhares-ES, a similar climatological region to the present work, revealed that ETa, in average, was 27,8% and 26,0% higher in the conventional sprinkler system when compared to those irrigated through drip and microjet irrigation system, respectively.

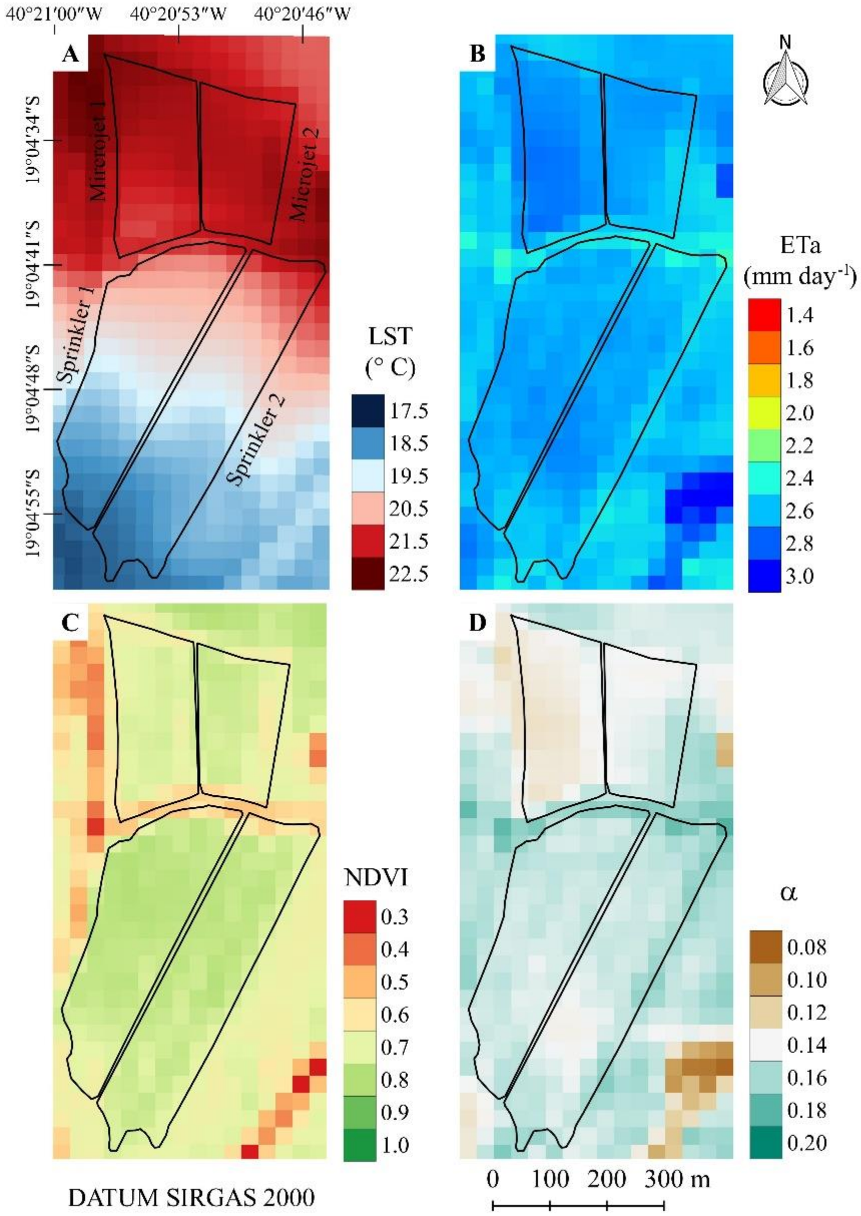

Figure 2. Maps of Land Surface Temperature (A), actual evapotranspiration (B), Normalized Difference Vegetation Index (C) and, albedo (D) for robusta coffee areas irrigated by the sprinkler and microjet irrigation systems.

Additionally, low values of ETa are concentrated in the border of areas, especially in the sprinkler 2 area, due to superposition deficiency in this zone. Regarding to NDVI, more variability is observed in microjet than sprinkler areas (Figure 2C). Although microjet be an efficient irrigation system in terms of water saving, it’s very common coffee farmers commenting that under this system, the coffee growth less than in sprinklers systems. Regarding to surface albedo (α), the amount of sunlight that is reflected back from a surface or a substance (Gueymard et al., 2019), ranged from 0.08 to 0.2, interval compatible to the findings of Costa et al. (2019). It’s was also verified that areas on sprinkler presented a higher values (Figure 2D) compared to microjet. These results, among other factors, it’s because of a higher soil cover in this areas than microjet. Once the soil of study area is predominantly dark clay, which presents a lower albedo than green vegetation (An et al., 2017). In general terms, all remote sensing variables presented low variability.

Table 1 shows the descriptive statistics of microjet and sprinkler irrigated areas. The comparison of the two irrigation systems, based on mean values, revealed these irrigated areas presents very close ETa values. This is as consequence of very similar planting date and also due to develops in the same edaphoclimatic conditions. These ETa values for this period (winter) are in accordance with reported by Costa et al. (2018) using SEBAL model and Lena et al. (2011) using lysimeter, both in arabica coffee.

Table 1. The summary descriptive statistics of microjet and sprinkler irrigated areas.

Field	Min	Max	Range	Mean	SD
Land Surface Temperature (°C)					
Sprinkler 1	18.351	20.832	2.481	19.755	0.723
Sprinkler 2	18.124	21.418	3.294	19.463	0.922
Microjet 1	21.225	22.097	0.872	21.665	0.243
Microjet 2	21.505	21.970	0.465	21.734	0.099
Actual Evapotranspiration (mm day^{-1})					
Sprinkler 1	2.562	2.684	0.122	2.637	0.026
Sprinkler 2	2.531	2.717	0.186	2.613	0.047
Microjet 1	2.656	2.770	0.113	2.717	0.033
Microjet 2	2.529	2.683	0.154	2.633	0.044
Normalized Difference Vegetation Index					
Sprinkler 1	0.837	1.000	0.163	0.926	0.048
Sprinkler 2	0.682	0.984	0.302	0.839	0.085
Microjet 1	0.628	0.735	0.107	0.707	0.021
Microjet 2	0.706	0.787	0.081	0.748	0.021
Surface Albedo					
Sprinkler 1	0.145	0.156	0.010	0.151	0.003
Sprinkler 2	0.137	0.163	0.026	0.152	0.006
Microjet 1	0.129	0.141	0.012	0.135	0.003
Microjet 2	0.140	0.158	0.018	0.146	0.005

Regarding the LST, microjet-irrigated areas presented a lower variability and higher values than sprinkler-irrigated areas (Table 1). As expected, because microjet irrigates only part of the soil, as previously discussed. Then, LST product available in the EEFlux derived from Landsat images can be an important tool to detect different irrigation methods in large coffee areas, such as in the northern region of the Espírito Santo State, as well as, be an indicator of water stress in a robusta coffee and, consequently of the coffee growth variability (using time series).

It was in the NDVI where the difference between areas was more pronounced, with a mean values of 0,883 for sprinkler-irrigated, while the microjet areas was 0,728. These results revealed that coffee plantations irrigated by sprinkler systems can be more positive and significant impact than microjet on the coffee yield. However, it's important to mention that there are other facts (e.g., variety, fertilization management, tree pruning, etc.), can also strongly impact on the NDVI values.

Regarding to microirrigation compared to sprinkler irrigation systems, it uses less amount of water per unit of yield and reduces water losses through evaporation and deep percolation (Lena et al., 2011). Thus, microirrigation leads to substantial water savings, releasing the saved water to the environment or to other uses (Perry & Steduto, 2017). Regarding to surface albedo (α), we verified higher values than sprinkler areas, as already discussed previously, however, the differences between average values are very slight. Figure 3 shows the correlation matrix between remote sensing variables for robusta coffee areas irrigated by sprinkler and microjet systems.

The correlations behavior between variables were very similar for both systems (Figure 3A and B), being the higher positive correlation observed for the NDVI-ETa (r = 0.62) followed by Albedo-LST to the sprinkler irrigation. In was verified the opposite to the microjet, i.e., the higher "r" value verified in Albedo-LST (r = 0.8) and, followed by NDVI-ETa. When is analyzed the negative correlation, the Albedo-ETa showed strongly negative correlation for both systems (r > - 0.9).

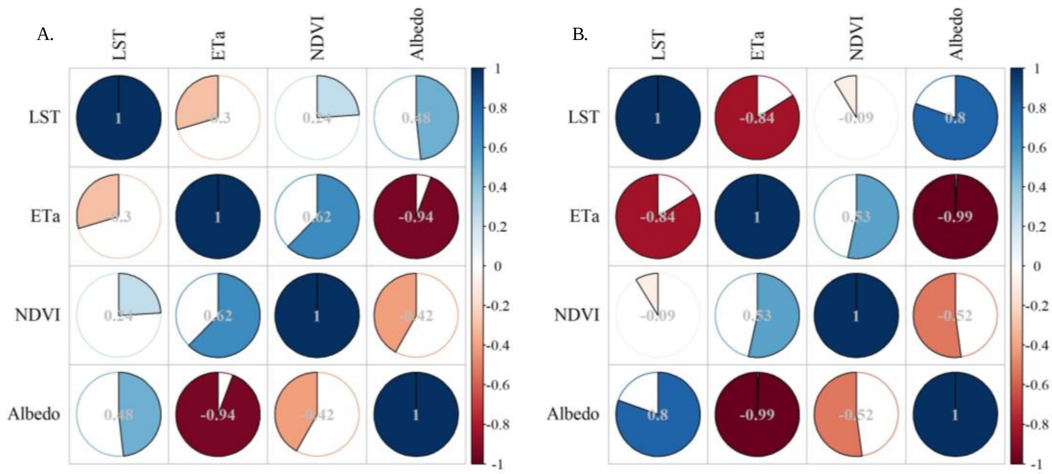

Figure 3. Correlation matrix between remote sensing variables for robusta coffee areas irrigated by the sprinkler (A) and microjet (B) irrigation systems.

The majority of the scientific studies have been focused on the relationship between vegetation indices and LST (Deng et al., 2018; Karnieli et al., 2010; Vlassova et al., 2014; Yuan & Bauer, 2007), since that LST can reflect the land surface water-heat exchange process comprehensively, which is considerably significant to the study of environmental changes (Deng et al., 2018), while the vegetation indices represents the vegetation vigor properly and other biophysical parameters of vegetation such as biomass, leaf area, etc. In this present study NDVI-LST shows positive, but low, correlation (0.24) for sprinkler system, while microjet a very low negative correlation (-0.09).

Lastly, it's important to use an irrigation system in coffee plantations in north region of Espírito Santo State, even if it's sprinkler, which clearly have a greater water consumption than microirrigation. The irrigation adoption is necessary due to heterogeneous rain characteristics in this State, being 58% of this area, mainly in the north part, presents high climatic risk of drought in the phases of the flowering, bean formation and vegetative growth (Pezzopane et al., 2010).

CONCLUSIONS

Microjet-irrigated areas have higher LST and lower NDVI values than sprinkler-irrigated areas, on the other hand, ETa was very similar. The use of LST, ETa, and NDVI available at EEFlux platform showed to be important indicators of irrigation management variability and coffee development at farm-scale. However, this region of Espirito Santo state have high cloud presence over all year, this condition can obstruct an effective monitoring during crop development.

Regardless, future research is needed in this region involving larger areas long periods for understand better the spatial and temporal dynamics of these and other variables in irrigated-areas of robusta coffee, generating knowledge that can be applied to evaluate decision support strategies related to irrigation. In addition, there is a lack of scientific data of remote sensing (as that mentioned in this study) about coffee robusta plantations, which is essential for understudying of this crop development and production , being also important studies with these focus.

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