

MODIS IMAGES FOR AGROMETEOROLOGICAL MONITORING OF COFFEE AREAS

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ABSTRACT: Agrometeorological monitoring of coffee lands has conventionally been performed in the field using data from land-based meteorological stations and field surveys to observe crop conditions. More recent studies use satellite images, which assess large areas at lower costs. The *Moderate Resolution Imaging Spectroradiometer* (MODIS) sensor of the Earth satellite provides free images with high temporal resolution and vegetation specific products, such as the MOD13, which provides the *Normalized Difference Vegetation Index* (NDVI) processed in advanced. The objective of this study was to evaluate the relation between the NDVI spectral vegetation index and the meteorological and water balance variables of coffee lands of the south of Minas Gerais in order to obtain statistical models of this relationship. The study area is located in the municipality of Três Pontas, Minas Gerais, Brazil. The statistical models obtained demonstrate a significant negative correlation between the NDVI and water deficit. NDVI values under 70% may represent a water deficit in the coffee plants. The models developed in this study could be used in the agrometeorological monitoring of coffee lands in the south of Minas Gerais.

Index terms: Coffee, remote sensing, water balance, NDVI.

IMAGENS DO SENSOR MODIS PARA MONITORAMENTO AGROMETEOROLÓGICO DE ÁREAS CAFEIEIRAS

RESUMO: O monitoramento agrometeorológico de áreas cafeeiras tem sido realizado convencionalmente em campo utilizando-se dados de estações meteorológicas terrestres e visitas à lavoura para se observar seu desenvolvimento. Estudos mais recentes utilizam imagens de satélite, que permitem avaliar grandes áreas a custos menores. O sensor *Moderate Resolution Imaging Spectroradiometer* (MODIS) do satélite Terra oferece gratuitamente imagens com alta resolução temporal e produtos voltados especialmente para vegetação como o MOD13, que fornece o índice de vegetação *Normalized Difference Vegetation Index* (NDVI) previamente processado. Objetivou-se, no presente estudo, avaliar a relação entre o índice de vegetação espectral NDVI e as variáveis meteorológicas e do balanço hídrico, em áreas cafeeiras do sul de Minas Gerais, visando à obtenção de modelos estatísticos dessa relação. A área de estudo localiza-se no município de Três Pontas, estado de Minas Gerais, Brasil. Os modelos estatísticos desenvolvidos demonstram a correlação significativa negativa entre o NDVI e déficit hídrico. Valores de NDVI menores que 70% podem indicar a deficiência hídrica de cafeeiros. Os modelos desenvolvidos no presente estudo poderão ser usados no monitoramento agrometeorológico de lavouras cafeeiras na região sul de Minas Gerais.

Termos para indexação: Café, sensoriamento remoto, balanço hídrico, NDVI.

1 INTRODUCTION

The successful cultivation of coffee depends on the monitoring of climatic conditions throughout plant development. Conventionally, this monitoring has been conducted in the field using data from weather stations and visits to the plantation to observe its development. However, more recent studies using satellite imagery for assessing large areas at a lower cost. The *Moderate Resolution Imaging Spectroradiometer* sensor (MODIS) in Terra satellite provides free images with high temporal resolution and products geared especially for vegetation as the MOD13, which

provides *Normalized Difference Vegetation Index* (NDVI), every 16 days in advance processed (DISTRIBUTED ACTIVE ARCHIVE CENTER - DAAC, 2011). The vegetation index is a technical enhancement of vegetation by means of simple mathematical operations used in digital processing of remote sensing images, in order to analyze different spectral bands of the same scene simultaneously (HILL, DONALD, 2003). The NDVI is sensitive to the presence of chlorophyll and other pigments vegetation responsible for the absorption of solar radiation in the red band and has been used primarily to estimate biomass and changes in the development of plant communities

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(Fensholt ; NIELSEN ; STISEN , 2006; HUETE et al . 2002; Machado et al. 2,010 ; TUCKER et al. 2,005 ; ZHANG et al. 2,003) and second Hatfield et al. (2008) , the spectral vegetation index most widely used in agronomic research .

Liu, Massambani and Nobre (1994) claim that the annual variation of NDVI can be a good indicator of vegetation stress caused by regional climate changes. Schultz and Halpert (1995) observed the spatial relationships between NDVI, land surface temperature and precipitation data, as well as the potential for the combined use of NDVI and temperature data for bioclimatic monitoring in South America.

The aim of the present study was to evaluate the relationship between spectral vegetation index NDVI and meteorological variables and water balance in coffee areas in southern Minas Gerais, in order to obtain statistical models of the relationship.

2 MATERIALS AND METHODS

The study was conducted in a selected area in the municipality of Três Pontas, southern region of Minas Gerais. The city, which occupies an important position in the coffee producing state, is characterized by an average altitude of 900 m, the predominance of flat relief wavy and Oxisols (Vieira et al., 2007).

For the development of the work weather data collected by the Três Pontas Agricultural Cooperative (Cooperativa Agrícola de Três Pontas) were analysed, geographic coordinates latitude 21 ° 22 '16 "S, longitude 45 ° 29' 23" W and 920 m altitude, from January 2008 to December 2010.

Subsequently, analyzes were performed climatic water balance (BH) with the aid of the software Balanço Hídrico Sequencial, Versão 1.0, developed by Souza (2008), which is based on methodology adapted Thornthwaite and Mather (1955). The software used data of precipitation, reference evapotranspiration (ETo), crop coefficient (kc), available water capacity (CAD) and fraction of available soil water for the coffee culture.

The values of kc used to transform crop evapotranspiration ETo were based on publications by Sato et al. (2007) for the coefficient of the coffee crop during autumn-winter in Lavras, MG and Villa Nova et al. (2002), who estimated the coefficients of the coffee crop in function of the weather and agronomic parameters for the period from January to March and October to December (Table 1).

In the analysis of water balances conducted for the years 2008, 2009 and 2010, considered the amount of CAD 100 mm and fraction of available soil water 0.6, which represent the majority of soils found in coffee areas of the region (Meireles et al., 2009; SOUZA; Frizzone, 2007). Performed analyzes of daily water balance for the years 2008, 2009 and 2010, daily values of the components of the water balance were grouped into periods of 16 days.

For mapping the coffee crops grown (plants with more than 5 years) has created a geographic database system for information processing georeferenced Spring 5.0 (CAMERA et al., 1996). Selected areas in mapping are all, to a maximum distance of 10 km from the collection site meteorological data. The mapping of crops was done by visual interpretation of an image Landsat TM 5/sensor, orbit / point 219/75, the day 16/07/2008 with spatial resolution of 30 m, restored to 10 m. In this image were selected coffee areas larger than 10 ha. Subsequently, the selected areas were checked in the field with the aid of a GPS navigation and revisited periodically to monitor the conditions of crops and phenology of coffee.

In the analysis of spectral vegetation index product images were used NDVI / MODIS / Terra MOD13 with spatial resolution of 250 meters (DAAC, 2011). This product is generated from images acquired over a period of 16 days and the songwriting process selects the best image pixel to construct the product MOD13Q1, minimizing any spatial distortions, radiometric noise and atmospheric effects (HUETE et al., 2002).

TABLE 1 - Values of crop coefficient (kc) used in the analyzes.

Month	kc	Month	kc
Jan	0,89	Jul	0,62
Feb	0,87	Aug	0,62
Mar	0,91	Sep	1,17
Apr	0,94	Oct	1,03
May	0,88	Nov	0,9
Jun	0,62	Dec	0,95

MOD13Q1 72 images were analyzed for the study period, but 7 were discarded. NDVI values were obtained from two pure pixels for each image, randomly chosen within the limits of selected crops. 10 fields were chosen randomly, totaling 20 pixels per image. The NDVI images were converted to GeoTIFF using the software MRT (DAAC, 2011).

In the next step we analyzed the relationships between meteorological variables collected and estimated values of NDVI and phenology of coffee described by Camargo and Camargo (2001) and can be summarized as follows: Phase I - vegetation and formation of flower buds; stage II - induction and maturation of flower buds; phase - III - flowering and fruit expansion; phase IV - grain formation; phase V - fruit maturation; phase VI - home and senescence of quaternary and tertiary branches.

To analyze how the spectral variables and field correlated Pearson correlations were performed between the NDVI values of the coffee areas and meteorological variables in order to estimate the strength of association between variables. From the best correlation regression models were tested to fit the data. The relationship between variables was summarized through the scatterplot.

3 RESULTS AND DISCUSSION

In the present study conducted in the city of Três Pontas, southern Minas Gerais, it was found that the average air temperatures recorded in the years 2008, 2009 and 2010 were 20.6 °C, 20.6 °C and 21.2 °C, respectively. In the case of coffee (*Coffea arabica* L.), average annual temperatures great lie between 18 oC and 22 oC (Meireles et al., 2009). Therefore, the average annual temperature Three Tips for the years studied, falls in that range of optimal for the species. The total rainfall recorded in the years 2008, 2009 and 2010 were 1616 mm / year, 2089 mm / year and 1113 mm / year. Camargo and Camargo (2001) argue that the requirement of rainfall of Arabica coffee is highly variable, according to the phenological stage of the plant. In the vegetation period and fruiting, which runs from October to May, the coffee needs water available in the soil. At harvest time and rest, from June to September the need for water is small and the drought does not affect the production. The phenological cycle of coffee presents a succession of vegetative and reproductive phases that occur in about two years unlike most plants that emit the inflorescences in spring and fruiting phenology in the same year.

The calculation of the water balance showed that the values of actual evapotranspiration (ER) accumulated in the years 2008, 2009 and 2010 were 835, 912 and 794 mm, respectively. The values of water surplus (EXC) accumulated in the years 2008, 2009 and 2010 were 781, 1179 and 342 mm, respectively, and the water deficit (DH) accumulated in the same years were 63, 2 and 181 mm. This result demonstrates a great contrast to water availability between the three years analyzed. Figure 1 shows the variation of average air temperature, precipitation, evapotranspiration, water surplus and deficit accumulated for periods of 16 days.

Aiming to relate meteorological variables and terrestrial vegetation index NDVI derived spectral images of the MOD13 MODIS / Terra, Figure 2 shows the cumulative rainfall, the drought, the NDVI average and phenological phases of coffee during the study period. The average NDVI showed a maximum value of 83 % (April 2008 - end of rainy season) and minimum 50 % (September 2010 - the end of the dry season). It is also observed that when the accumulated rainfall in periods of 16 days are reduced to zero, the values of NDVI decrease slowly as a result of lower leaf area index of the coffee plantations in the dry season and the fall of leaves at harvest. According to Chapman and Thornes (2003), the seasonal or annual evolution of the degree of green vegetation inferred from NDVI responds intimately to the annual distribution of rainfall. NDVI may also be related to a reduction of photosynthetic force on coffee when subjected to water deficiency, as reported by Sims and Gamon (2002).

In 2008 there was the greatest amount of water deficit in September, 25 mm, and minimum NDVI value in the year of 60%. Coffee plants were monitored phases of bud maturation (II) and rest and senescence of tertiary and quaternary branches (VI) and water deficit did not hurt production. In 2009 there was drought and NDVI least 67%, occurred in September. In 2010 the drought was accentuated with highest value in September, 36 mm, related to NDVI minimum value of 50% for the year. Coffee plants were monitored phases of bud maturation (II) and rest and senescence of tertiary and quaternary branches (VI) and drought lasted until the beginning of phase I and III without prejudice to flower. Analyzing the variability of NDVI from AVHRR / NOAA about Brazil, Gurgel, Ferreira and Luiz (2003) observed for the Southeast region, set an annual cycle, with maximum values of NDVI between March and May and a minimum in September, end of drought period.

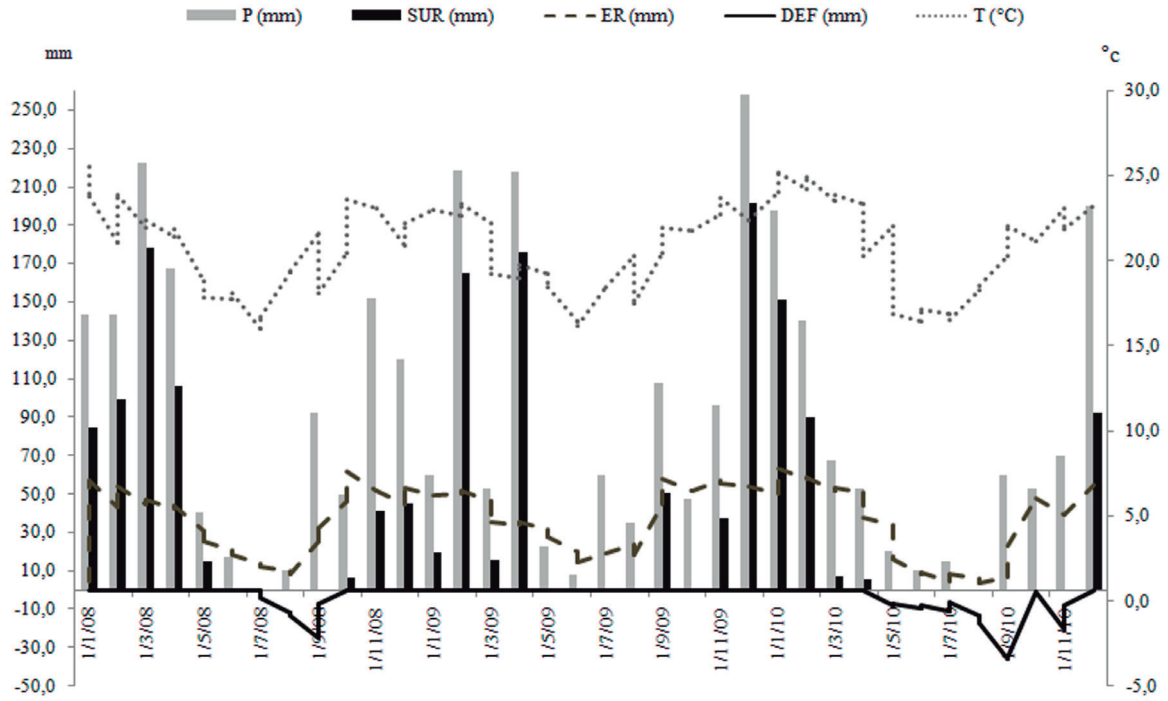


FIGURE 1 - Changes in mean air temperature (TM), precipitation (P), evapotranspiration (ER), excess (EXC) and water deficit (DEF) for periods of 16 days, years 2008-2010, in Três Pontas, MG.

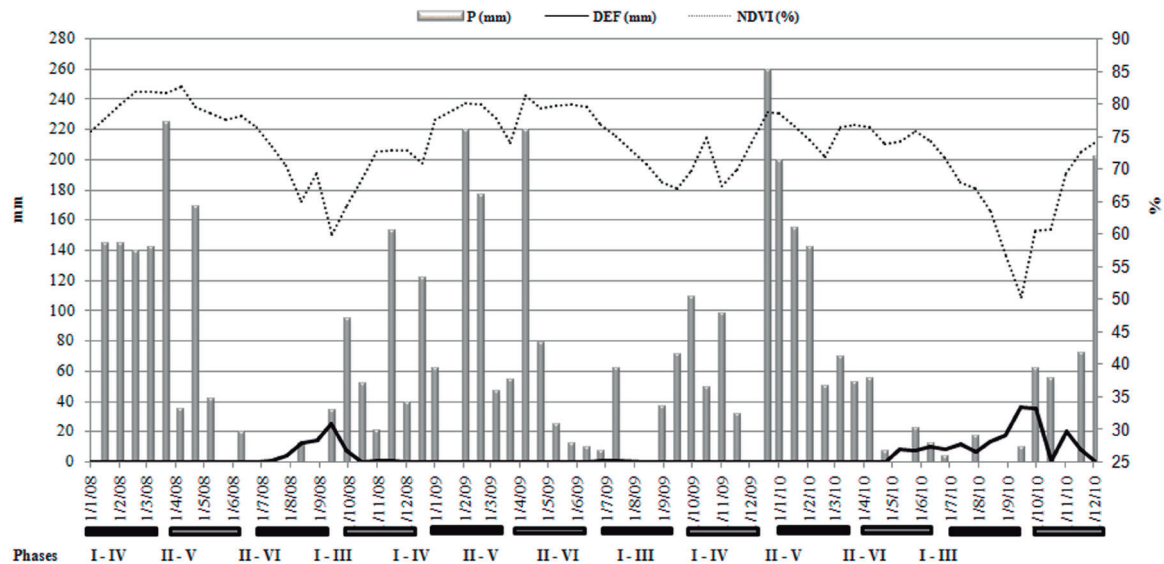


FIGURE 2 - Change in precipitation (P), water deficit (DEF) and the average NDVI for periods of 16 days and phenological phases of coffee, in the years 2008, 2009 and 2010 in Três Pontas, MG.

After analyzing the temporal dynamics of climate variables and spectra were performed Pearson correlations between the values of NDVI average coffee areas and meteorological variables, average temperature (TM) and accumulated precipitation (P), and the resulting water balance (BH), actual evapotranspiration (ER), water surplus (EXC) and water deficit (DEF) for the period 2008-2010 (Table 2) in order to estimate the strength of association between variables. For these years, the results indicated a weak correlation between NDVI and precipitation, air temperature, actual evapotranspiration and water excess. The opposite was observed between NDVI and water deficit.

Table 3 shows the linear regression models between NDVI and drought and their respective coefficients of determination, since these had better fit.

Liu and Ferreira (1991) correlated the NDVI with precipitation, potential evapotranspiration and water deficit generated in three regions of the state of São Paulo and found a better correlation between NDVI and water deficit.

Chen, Huang and Jackson (2005) estimated the water content of corn and soybean as NDVI from MODIS and found correlation coefficients above 0.70.

Figure 3A shows the behavior of water deficit values obtained from the climatic water balance and estimated in terms of the average NDVI. It is observed that NDVI values less than 70% expect the occurrence of drought. In the period from August to December 2009 models estimated the occurrence of drought in some periods, without being observed in the field. This estimate is directly related to the decrease in NDVI values due to reduced leaf area occurred during the harvest period and phenological stage VI of coffee (home and senescence of the branches).

Figure 3B shows the scatter diagram that summarizes the relationship between the variables, water deficit observed and estimated from the NDVI. We observe a positive relationship between water deficit calculated and estimated from the NDVI (DEF DEF est est 1 and 2). There were periods when water deficit values were underestimated compared to observed.

TABLE 2 - Coefficients of Pearson correlation to analyze the relationship between NDVI and meteorological variables in the period 2008-2010.

CORRELATED VARIABLES	CORRELATION COEFFICIENT (r)
TM X NDVI	0,1616
P X NDVI	0,3989
ER X NDVI	0,3669
DEF X NDVI	-0,7224*
EXC X NDVI	0,4609*

n = 65; * values significant at 5% probability TM = average temperature, P = accumulated rainfall, ER = actual evapotranspiration, water deficit DEF =; EXC = water surplus.

TABLE 3 - Regression models and their coefficients of determination in the period 2008-2010.

MODELS	DETERMINATION COEFFICIENT (r ²)
$DEF_1 = -0,865 NDVI + 67,13$	0,524*
$DEF_2 = 0,040 (NDVI)^2 - 6,449 NDVI + 259,2$	0,623*

(n= 65, * values significant at 5% probability)

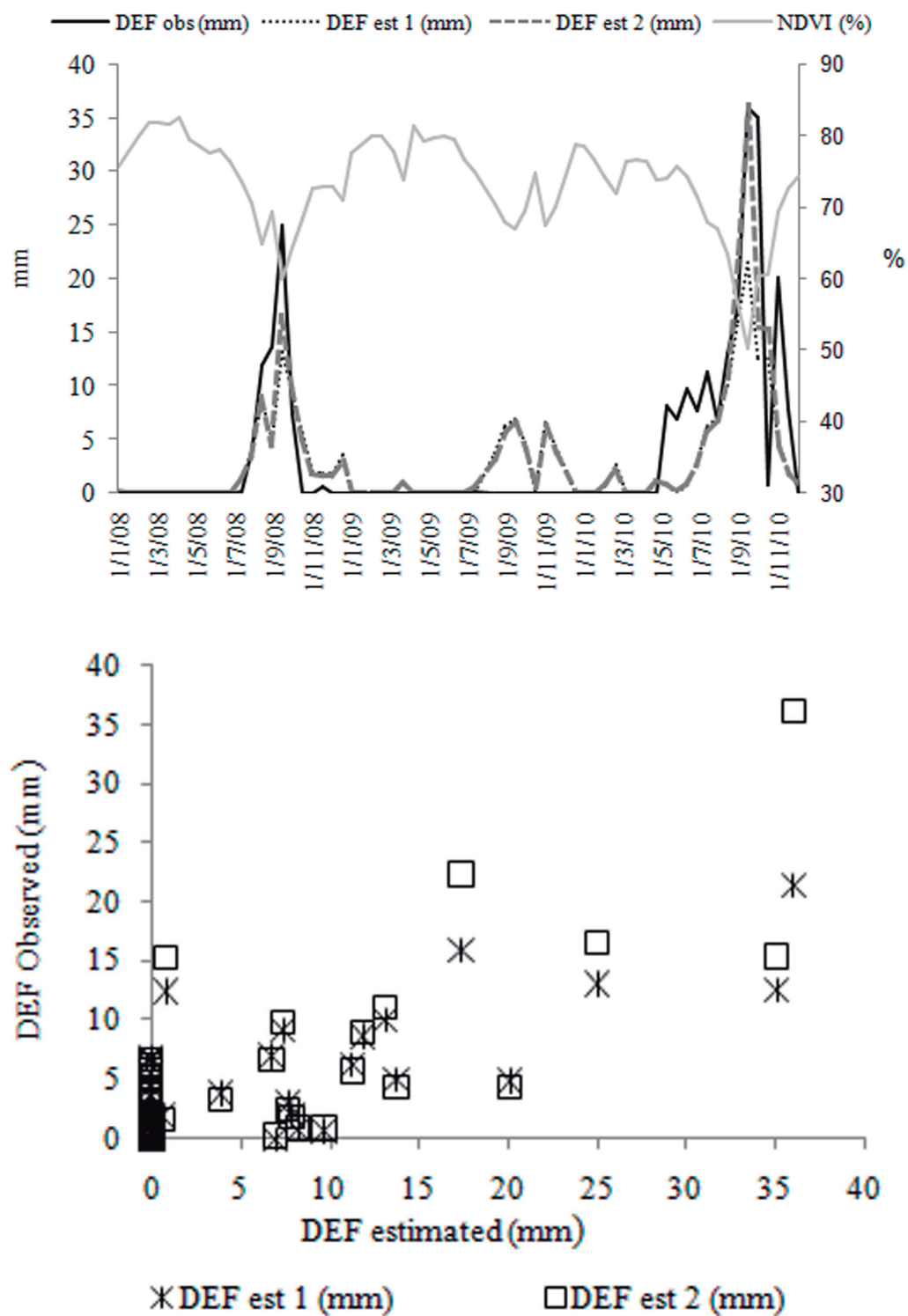


FIGURE 3 - A - Behaviour of water deficit values observed and estimated (DEF DEF est est 1 and 2) as a function of average NDVI.

B - Dispersion of water deficit values observed and estimated (DEF DEF est est 1 and 2) as a function of NDVI.

4 CONCLUSIONS

The product MOD13 images of MODIS / Terra has the potential to assist in the monitoring of drought in coffee areas. The statistical models developed demonstrate the significant negative correlation between NDVI and water deficit. NDVI values lower than 70% may indicate water deficiency of coffee.

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