# Water footprint of Arabica coffee from "*Matas de Minas*" under shade management[1]

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## ABSTRACT

Studies related to climate change and agricultural value chains have in common the growing concern on conserving water resources. Thus, the concept of the water footprint stands out, which measures the amount of water (in volume) necessary to produce a unit (in mass) of a given product. Among Brazilian agricultural activities, coffee farming emerges as one of the most important, even though the crop is sensitive to potential climatic changes, especially to the increase in temperature and periods of drought. An alternative to mitigate the effects of climate change is shade management, which is common in agroforestry systems. Therefore, the objective of this study was to evaluate the influence of shade management on the water footprint of coffee activity in the region of "*Matas de Minas*". The water footprint was calculated for the field and product processing phase. Despite reducing the evapotranspiration of the coffee plant, shade management provided an increase in the water footprint, since it decreased the crop yield. The water footprint data obtained are expressive, with a calculated value of 13,862 $m^3 t^{-1}$ for full sun management and 16,895 $m^3 t^{-1}$ for shade management, in which both are the most recommended for the agricultural sector.

**Keywords:** shading; climate changes; water resources; coffee crop

## INTRODUCTION

Due to the current concerns with environmental issues, new concepts have emerged seeking indicators to assess the environmental sustainability of economic activities. One of these concepts is "Water Footprint", a term introduced by Hoekstra and Hung (2002) from the perspective of the use and international trade of water through the production chains. Water footprint is defined as the amount of fresh water embedded in the entire production process to obtain an individual good or service or even from a country and is also called virtual water (Chapagain & Hoekstra, 2007).

Agriculture is an activity that requires a large volume of water; however, the use of this natural resource is not considered in the final price of the products. This is worrisome for countries like Brazil, which is major world producer of commodities, such as coffee, which is one of the main agricultural export products.

Coffee crop requires a great water availability in the soil. The requirement for water for the crop is known as the "green water footprint" and is obtained via precipitation. However, the water consumption of the coffee activity is not supplied only by the rain, since irrigation may be necessary, and to reach the final product, coffee crop still goes through other production stages (Silva *et al.*, 2014) that demand water consumption (blue water footprint) and can generate wastewater (gray water footprint).

Due to its high consumption, it is necessary to carry out an assessment of the sustainability or viability of the coffee activity in relation to water resources. In order to compose the total coffee water footprint, the total water expenses in the different production stages are calculated,

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starting from the field to the final product by adding all the water footprints. This value is an important benchmark, and it is noteworthy to be discussed as a component in the final cost of the product, a fact that is not yet a reality in the international market of coffee and other commodities. This is especially important due to the global water scarcity, and ways of incorporating the added value of water into the production of agricultural crops should be assessed. All this virtual water necessary for coffee production makes Brazil not only a major food exporter, but also a major exporter of water.

Although coffee crop is one of the most developed activities in Brazil, crop yield can be severely affected in periods of prolonged water scarcity, especially in areas where coffee plants are not irrigated (Ronchi *et al.*, 2015). Water stress has an inhibiting effect on photosynthesis and, therefore, affects crop survival and productivity (Araújo & Demincis, 2009).

In addition to increasing periods of drought, global climate changes are potentially associated with an increase in the average temperature of the planet. Hence, the search for adaptive or mitigating techniques for these effects in crops are of national importance, such as coffee, is relevant, with special attention to shade management in coffee crop (Camargo, 2010). Shade management aims to reduce the temperature in the coffee crop and, at the same time, reduce the water consumption (Damatta & Ramalho, 2006).

Therefore, the hypothesis of this study is that shade management can reduce the evapotranspiration demand of the coffee plant and reduce the water footprint of the crop. The present study aimed to assess the total water footprint of coffee plants grown under shade management in the region of "*Mata de Minas*" located in the state of Minas Gerais, Brazil.

## MATERIAL AND METHODS

The study was carried out on a farm with *Coffea arabica* crop located at the coordinates 20° 52 '26 "S and 42° 58' 48"E, in the municipality of Paula Cândido located in the state of Minas Gerais, in the region known as the *Matas de Minas* (Figure 1). This is known for special coffees produced in the mountain in 63 municipalities, located in the Atlantic Forest biome, in the southeast region of Minas Gerais.

The soil in the area was classified as a clayey Red-Yellow Latosol according to the Brazilian System of Soil Classification (EMBRAPA, 2018). The local altitude of the property is 650 m, and the climate of the study region is of Cwb type, which is a tropical altitude climate (Alvares *et al.*, 2013).

Coffee in full sun and shade management, were selected in the experimental area provided by a black mesh shading screen with 40% of radiation interception installed in July 2016. In both areas, plants of IAC-125 RN variety of 5.5 years of age were cultivated at 2.8 m between the lines and 0.7 m between plants, totaling approximately 5,100 plants per hectare.

To calculate the water footprint, productivity data from 2018 harvest (two years after installing the black mesh shading screen) were used, in which 88 sc $ha^{-1}$ were obtained in full sun management, and 66 sc $ha^{-1}$ in shade management.

The average water consumption in the coffee washer used to process coffee beans was estimated. The coffee washer used on the property is a mechanical type, which uses 0.3 L of water per $dm^3$ of washed coffee. The grains were peeled by wet using an average of 3 to 5 L of water per $dm^3$ of coffee to be peeled when water cannot be reused (Matos, 2008). A system that reuses the water from the coffee washers was adopted on the farm, known as wastewater treatment system (SLAR, acronym in Portuguese) (Silva et al, 2014.). The dimensioning of the SLAR system works with approximately 76% of the water in the grain washing step, with the total water consumption reducing to approximately 0.6 to 1 L of water per $dm^3$ of produced coffee (Silva *et al.*, 2014; Soares *et al.*, 2013). All the effluents from the processing are collected and applied to the crop via fertigation.

The wastewater from the coffee washing and pulping processes (gray water footprint) is reused by adopting the practice of fertigation in a field, which was not used in the present experiment. In order to calculate the final water footprint of the studied treatments, only green and blue water footprints were considered.

In the green water footprint estimate, data from climate devices were used, and the Hargreaves and Samani method was choosen to calculate the evapotranspiration (ET) accumulated over a year (2017/2018). A weather station (Irriplus, model E-5000) recorded the daily precipitation data, and a HOBO Data Logger H21-USB registered the air temperature and dew point every minute. All instrumentation was installed in each treatment´s centre area (shaded and non-shaded coffee crop) in the interrow center.

This Hargreaves and Samani method was chosen because it presented a good correlation with the standard method (Penman-Monteith-FAO) when it is used for dry climates (Hargreaves & Allen, 2003). According to the meteorological station data record, the accumulated rainfall during the crop year was 677 mm in full sun management and 588.7 mm in the shade management. Despite the historical series indicating a tropical altitude climate (Alvares *et al.*, 2013), the anomaly that occurred during the evaluation period would approach a dry climate, since the average precipitation in the region is around 1,350 mm (Guimarães *et al.*, 2010).

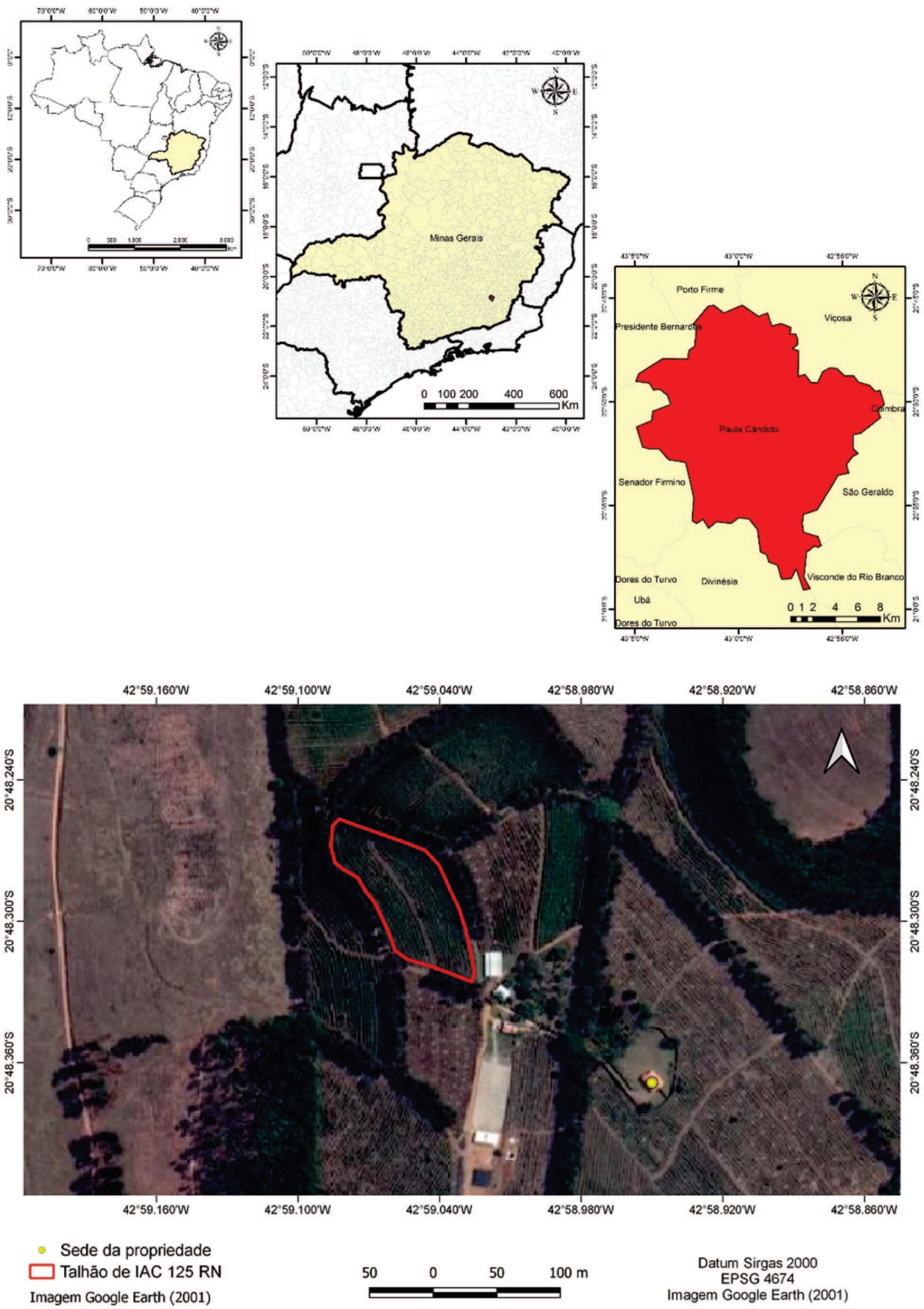


**Figure 1:** Site location considering the Paula Cândido municipality in the Minas Gerais State, Brazil, and the indication of the IAC 125 RN variety of *Coffea arabica,* where shaded and non-shaded plots were located.

The use of Hargreaves and Samani method is supported after the study carried out by França Neto *et al.* (2011) for eight cities of different regions of two Brazilian coffee regions (Cerrado, East, South and Zona da Mata of Minas Gerais, and West and Southwest Bahia). For all locations studied, the authors concluded that the estimate by this method adjusted better to the Penman-Monteith and recommend it use when and where climate data availability is limited.

We use 0.88 as the crop coefficient to transform the reference evapotranspiration (Eto) into crop evapotranspiration (ETc). This Kc was choosen considering the higher value available at Pereira *et al.* (2007) (page 105), obtained for *Coffea arabica* crop with similar age (5 years old), cultivated in the same Southeast region of Brazil, in a low rain year, and in a similar altitude (Ituverava-SP is at 631 m and our site is at 650 m). Using the maximum value (0.88) is justified because we have more plants per hectare than that study considered.

The results of ET were transformed into water volume per hectare ($m^3$ $ha^{-1}$) and calculations were performed according to the methodology described in Chapagain and Hoekstra (2007), considering the average of product fraction (pf) yield in the washing stage (0.9), pulping or peeling (0.44), degumming (0.9) and drying (0.50) for coffee produced in Brazil. According those authors, “product fraction in a certain processing step is the ratio of the weight of the resulting product to the weight of the original product”.

In calculating the blue water footprint, only the water consumed by the washer and peeler was used, since the plots are not irrigated. Considering the adoption of volume of coffee per volume of water used in the process, the production data were transformed into the volume unit. In calculating the volume of coffee, a density of 0.7 g $cm^{-3}$ was used for the raw product, according to the Brazilian Health Regulatory Agency (CNNPA-MS, 1978). Thus, the production of raw coffee in tons was transformed into production in cubic meters, with the subsequent transformations according to the average coefficients of product yield as described (Chapagain & Hoekstra, 2007).

From the data obtained, it was possible to calculate the water consumption of the entire coffee production chain, from the field to the drying phase. The calculation of the water footprint considered the volume of water used to produce one ton of processed coffee ($m^3$ $t^{-1}$). The total water footprint considered the sum of the green and blue water footprints.

## RESULTS AND DISCUSSION

Coffee production has a high demand of water resources (Table 1). Figure 2 shows how the virtual water content of coffee was calculated in both coffee crop management. Coffee plant in full sun management, despite having a higher ET, provided a smaller water footprint in relation to the shade management, since it presented greater productivity.

The effect of shade management on reducing coffee crop productivity has also been identified in studies in Brazil (Campanha *et al.*, 2005; Jaramillo-Botero *et al.*, 2010) and Costa Rica (Vaast *et al.*, 2006). On the other hand, this negative effect cannot be generalized, as revealed by studies carried out in the state of Paraná (Morais *et al.*, 2009) and Mexico (Soto-Pinto *et al.*, 2000). Brazilian studies found no effect of shade management in the production and on the other hand, Mexican studies found an increase. In addition, it is noteworthy to consider other potential positive effects of shade management in coffee crops, such as improving coffee quality (Vaast *et al.*, 2006, Mancuso *et al.*, 2013) and ecosystem production (Perfecto *et al.*, 2005; Souza *et al.*, 2012).

Regarding the assessment of the green water footprint, the results obtained are related exclusively to the shade management and its consequences on the studied crop. This can be ensured, since IAC-125 RN variety in the two situations evaluated, full sun and shade management, were close to each other and they were subject to the same climatic conditions, soil type, landscape position and exposure to solar radiation. In this scenario, the evapotranspiration demand of the shaded plants was affected by reducing radiation due to the restricted light availability. However, this reduction in evapotranspiration did not decrease the water footprint as previously hypothesized, since shade management reduced productivity and, showed less efficiency in the use of water per ton of processed coffee. Shade management increased the coffee green water footprint by approximately 18%.

The largest consumption of water in the coffee production chain is found in the field phase (Table 1, Figure 2), caused primarily by the evapotranspiration demand of the crop. This volume of water is not included in the production costs and is not part of the final value of the product. This result attracted the attention of many experts that discussed the effective sustainability in production processes, since the production does not occur without the required water needed.

The post-harvest stages of coffee consume little volume of water when compared to the period of cultivation in the field (Figure 2). Even if all the post-harvest processing stages of the coffee were carried without using water, a small reduction in the total water footprint would be verified, since the blue water footprint when the processing is done by wet means represents only 0.34% of all the water required in the cultivation of the crop (Chapagain & Hoekstra, 2007). This average data obtained by authors from the Netherlands who evaluated the water

**Table 1**: Green, blue and total water footprint for processed coffee, productivity and evapotranspiration (ET) under two crop management (full sun and shade management)

| Crop Management | Water Footprint | | | Productivity | ET |
|---|---|---|---|---|---|
| | Green | Blue(1) | Total | | |
| | | $m^3$ $t^1$ | | bags $ha^{-1}$ | mm $year^{-1}$ |
| Full Sun | 13,852.9 | 9.28 | 13,862.2 | 88 | 1,325.8 |
| Shade | 16,886.1 | 9.28 | 16,895.4 | 66 | 1,213.7 |

footprint of coffee from different producer countries confirms the data obtained in the present study, in which the blue water footprint represented only 0.07% and 0.06% of the requirement of water, values obtained in coffee plants grown under full sun and under shade management, respectively. The data of the Dutch authors and those of the present study coincide in establishing that the stage of crop cultivation consumes more than 99% of the water required to produce coffee.

Although the blue water footprint contributes little to the overall water footprint in the coffee crop, it is noteworthy the importance of technologies aimed at reducing and/or the rational use of water in the production chain, especially in the current scenario of a large water deficit in most of the Brazilian territory. Therefore, if 76% of reduction in water consumption in the coffee washing process with the SLAR system is done, it would save 29.4 $m^3$ $t^{-1}$ of water.

Water footprint values obtained for coffee produced in both managements (Table 1, Figure 2) are consistent with the results found in literature. In the coffee production for exportation, Chapagain and Hoekstra (2007) indicate a water footprint of 16,844.0 $m^3$ $t^{-1}$, considering the field activities up to the degumming phase.

The lower total water footprint in full sun management is primarily due to the higher average final productivity achieved in this treatment, a factor that contributed greater evapotranspiration of this management practice. Thus, higher productivity of 3.98 t $ha^{-1}$ in coffee grown under full sun management reduced the water waste per ton of processed coffee. Both water footprint (grain without toasting) in full sun management (13,862.2 $m^3 t^{-1}$) was lower than indicated by Chapagain and Hoekstra (2007) and in the shade management (16,895.4 $m^3$ $t^{-1}$) were less than indicated for the Brazilian coffee that is exported to the Netherlands (18,925.0 $m^3 t^{-1}$).

Water footprint chains in plants is typically less than estimated for livestock production (Mekonnen & Hoekstra, 2010). However, when compared to virtual water used in coffee production, independently of the management evaluated in this study, overcomes the water footprint of poultry (4,474.0 $m^3 t^{-1}$) and pork (7,208.0 $m^3 t^{-1}$). From the values found in the literature for Brazilian value chains (agricultural and livestock), only beef production

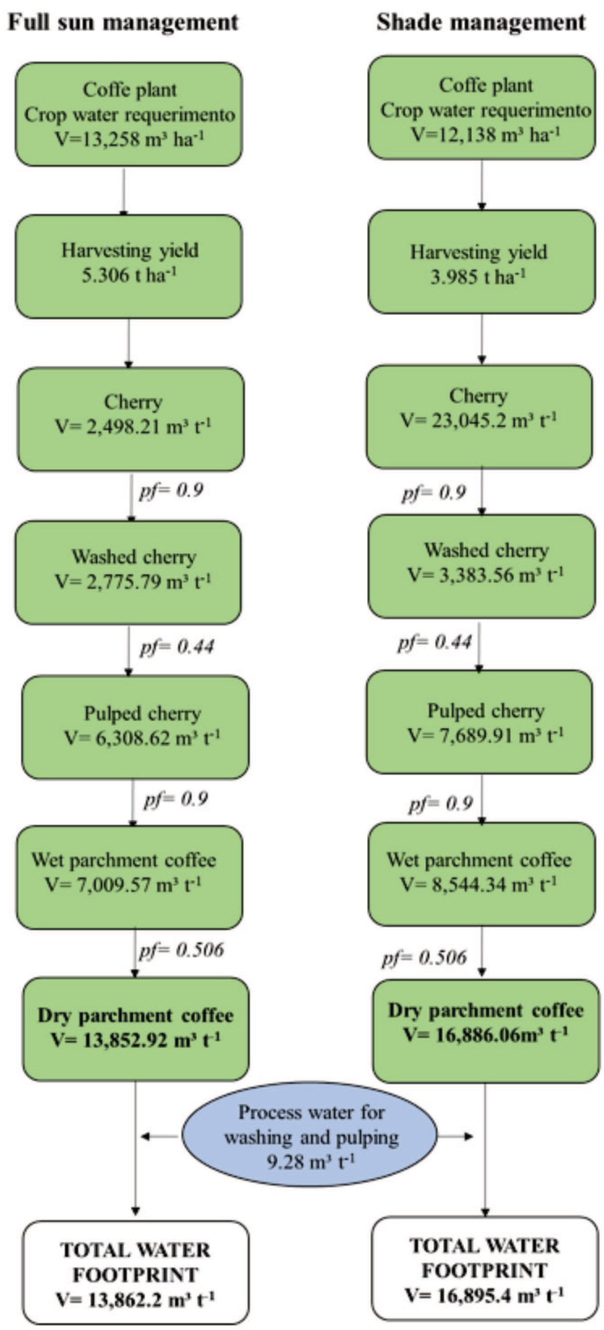


**Figure 2:** Steps representation of the water footprint of coffee under different crop management (full sun and shade), from the field to the drying phase, considering the green and blue water. Values represented the volume of water used to produce one ton of processed coffee ($m^3$ $t^{-1}$). V = virtual water content ($m^3$ t $ha^{-1}$); *pf* = Product fraction (t per t of primary product).

around 19,500.0 $m^3 t^{-1}$ exceeds the water footprint of coffee (Hoekstra & Hung, 2002; Mekonnen & Hoekstra, 2010).

It is noteworthy that more than 99% of the water footprint in coffee crops estimated in the present study originates in precipitation or, capillary rise in the soil, both processes within the hydrological cycle. Even though it is not an irrigation product, it must be considered that it is a water consumption, which could have other destinations in the soil profile. The results obtained indicate that the simple increase in productivity leads to a decrease in the green water footprint, making water use more efficient. Thus, practices aimed at increasing production, as well as the proper soil use and management while preserving its good physical quality, and thereby increasing water infiltration, should always be employed in order to replace the soil water that is used by the crop.

One of the limitations of the present study was the use of data from only one farm and over a single harvest. The estimation of evapotranspiration (ET) depends on the monitoring microclimate conditions with specialized equipment, which makes it difficult to increase the number of observations. Even though, it is considered that the values are an important landmark for the discussions about water virtual present in Brazilian commodities, showing how Brazil exports water without measuring or valuing this precious natural resource. Water is a scarce input in the world and a proposal of a new logic in world trade should be encouraged by public and private managers in the country, in order to value and monetize the added value of virtual water present in exported agricultural products. The statement that “the water required to drink coffee in the Netherlands is not Dutch water” (Chapagain & Hoekstra, 2007) clearly states that in addition to agricultural products, Brazil also exports water, another nonvisible product cost and unpaid in the international market.

## CONCLUSIONS

The water footprint of the coffee crops is concentrated in the field production phase.

The reduction of the coffee water footprint can be achieved by increasing productivity.

When associated with productivity losses, the reduction of the evapotranspiration demand of the coffee plants with shade management is not able to reduce the water footprint of the crop.

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The authors declare that there is no conflict of interest.

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