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Technical Article

Water Footprint of soybean, cotton, and corn crops in the western region of Bahia State

Pegada Hídrica das culturas de soja, algodão e milho na região oeste do Estado da Bahia

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ABSTRACT

Water catchment to subsidize agricultural activities is estimated at 70% of world consumption. In the western region of Bahia, the main agricultural center of the state, there is intensive use of water for the production of agricultural commodities. In regions with high water demand, quantification of the use of this resource can be performed using anthropic pressure indicators, such as the Water Footprint. Thus, this work determined the Water Footprint of the soybean, cotton, and corn crops produced in the western region of Bahia State. In order to determine the Water Footprint, data of the environmental characteristics and crop production in the region were used, were obtained from different Brazilian public and private institutions. The calculation of Water Footprint of the crops was performed by the sum of the green, blue, and gray components. The average Water Footprint between 2012 and 2017 for soybean corresponded to 1,972.3 m^3 t^1, with cotton at 1,825.2 m^3 t^1, and corn 512.4 m^3 t^1. The analyses of the results and the comparison with the values of the Water Footprint of other regions demonstrate that the edaphoclimatic conditions of the western region of Bahia are propitious to the development of these crops.

Keywords: agriculture; agricultural commodities; water resources; water use.

RESUMO

A captação de água doce para subsidiar as atividades agrícolas é estimada em 70% do consumo mundial. Na região oeste da Bahia, maior polo agrícola do estado, verifica-se o uso intensivo de água para a produção de *commodities* agrícolas. Em regiões com elevada demanda de água, a quantificação do uso desse recurso pode ser realizada utilizando indicadores da pressão antrópica, como a Pegada Hídrica. Deste modo, este trabalho determinou as Pegadas Hídricas das culturas de soja, algodão e milho produzidas na região oeste do Estado da Bahia. A fim de se determinar a Pegada Hídrica foram utilizados dados das características ambientais e de produção das culturas na região, os quais foram obtidos de diferentes instituições públicas e privadas do país. O cálculo das Pegadas Hídricas das culturas foi realizado pela soma das componentes verde, azul e cinza. A Pegada Hídrica média entre 2012 e 2017 para a soja correspondeu a 1.972,3 m^3 t^1, sendo a do algodão de 1.825,2 m^3 t^1 e a do milho de 512,4 m^3 t^1. Na análise dos resultados obtidos e na comparação com os valores de Pegada Hídrica de outras regiões, demonstrou-se que as condições edafoclimáticas da região oeste da Bahia são propícias ao desenvolvimento dessas culturas.

Palavras-chave: agricultura; *commodities* agrícolas; recursos hídricos; uso da água.

INTRODUCTION

Conserving water in pursuance of the planet's sustainability, providing resources to ensure life, health, and economic activity, is a real and growing necessity today, due to the quantitative and qualitative shortage of supply sources. The use of freshwater is divided worldwide among domestic (8%), industrial (22%), and agricultural use (70%), the latter representing the highest consumption (GWS, 2012).

Brazil holds a prominent position in agriculture, with large productive areas, due to the availability of arable land and favorable natural resources (NEHRING, 2016). In the state of Bahia, the West region has gained greater importance as the main agricultural center, due to its edaphoclimatic characteristics, governmental incentive, research and social actors involved. Soybean, cotton, and corn are the main commodities produced in the region (AIBA, 2015).

The area occupied by soybean, cotton, and corn crops in that region grew from 289.7 thousand ha in 1988 to 1.99 million ha in 2016 (IBGE, 2016). For the production of these crops, in addition to the dependence on local edaphoclimatic conditions and production systems, large volumes of water are required when irrigation techniques are adopted in order to increase crop productivity (CHALLINOR *et al.*, 2014).

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Despite the agricultural development, the western region of Bahia, located in the Cerrado biome (known as the Brazilian savannah), has presented conflicts as well as controversial and relevant environmental issues, such as increased suppression of native vegetation, intense use of water resources for irrigation, irregular deforestation, and fires, among other actions that may further threaten the preservation of the environment.

In the pursuit for environmental conservation, the need to develop and apply techniques and tools for monitoring, controlling and efficiently using water has proved urgent. In this sense, the Water Footprint (WF) is presented as an indicator of water use, from the perspective of water use in production (VELAZQUEZ *et al.*, 2011).

WF is defined as an indicator of water use that considers not only its direct use by a consumer or a producer, but also its indirect use, being divided into three components: green, which comprises the amount of precipitation that is retained in the soil and used by vegetation; blue, which corresponds to the use of water from both surface and underground sources, captured and incorporated into the crops; and grey, which is the volume of freshwater needed to assimilate the pollutant load of the production process in order to meet the quality standards of the receiving water body (CHAPAGAIN *et al.*, 2006; HOEKSTRA *et al.*, 2011).

Thus, this work aimed to determine the WF of soybean, cotton, and corn crops produced in the western region of Bahia State.

METHODOLOGY

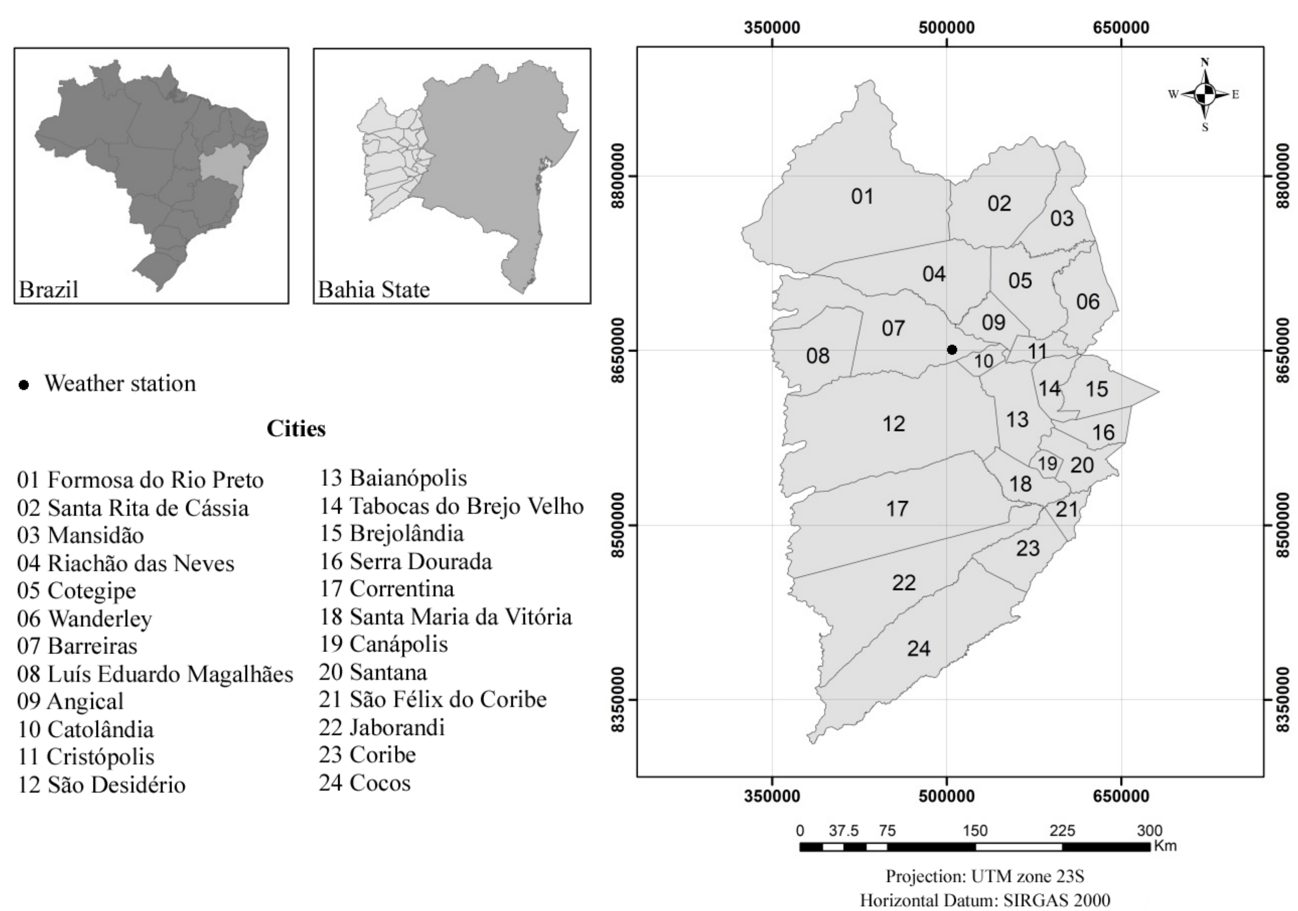
Area of study

This work was developed considering the productive areas with soybean, cotton, and corn crops in the western region of Bahia (Figure 1), the largest agricultural center of the state.

In the western region of Bahia, the planting systems used are in the rainfed and irrigated format. Rainfed cultivation is carried out only with the rain regime. The irrigated cultivation of soybean, cotton, and corn crops in the region is done by central pivots, occupying an area of 141,998 ha, mainly in the municipalities of Barreiras, São Desidério, Jaborandi, Riachão das Neves, Correntina, and Cocos (ANA, 2016).

Characterization of environmental and agricultural production variables

The climatic data of the region, used for WF calculation, were obtained from the National Institute of Meteorology (*Instituto Nacional de Meteorologia* – INMET), with the Barreiras-BA weather station regarded as a reference (OMM Code: 83236), located at the geographical coordinates of latitude 12°09'19,98"S; longitude 45°00'27,99"O; and altitude of 439 m (Figure 1). The average monthly data from 1988 to 2017 were used for maximum temperature (°C), minimum temperature (°C), air humidity (%), wind speed (m s^{-1}), solar radiation (h dia^{-1}), and precipitation (mm) — available at INMET (2017).



Source: elaborated by the authors.

Figure 1 – Location of western Bahia State.

According to the Soil Map of Brazil (SANTOS, *et al.*, 2011) the predominant soil class in the western region of the state of Bahia is the dystrophic Red Yellow Latosol. They are characterized by advanced weathering, granular structure, high hydraulic conductivity, high acidity, and low fertility. The available water capacity (AWC), which corresponds to the total amount of water stored in the soil and available to crops, was obtained from the work of Maluf *et al.* (2004). The maximum infiltration rate, which was based on soil hydraulic conductivity at saturation, was obtained from Gonçalves and Libardi (2013), as shown in Table 1.

Information on crop sowing and harvesting periods was obtained from the National Supply Company (CONAB, 2017), while data on crop coefficients (Kc), duration of developmental stages (initial, development, mid-season, final season), effective root depth, yield and response factor, as well as crop height were obtained from the Food and Agriculture Organization (FAO in ALLEN *et al.*, 2006).

The grey component of WF is calculated from data on nitrogen, the most widely used fertilizer in soybean, cotton, and corn crops, which were obtained, respectively, from Hoekstra *et al.* (2009), Chapagain *et al.* (2006) and Lourente *et al.* (2007). The application rate per hectare of agrochemical (in this case, nitrogen fertilizer) for each crop was obtained in EMBRAPA (2000), Steduto *et al.* (2012) and Coelho (2006), respectively. The maximum acceptable nitrogen concentration was determined by CONAMA's Resolution No. 357/2005 (CONAMA, 2005), which was the fraction of the runoff lixiviation and the natural concentration of pollutant in the receiving water body obtained from Hoekstra *et al.* (2011).

For the calculation of the WF components, the required information on crop productivity was obtained by crossing the data on planted area and production, generated in the historical series of municipal agricultural production, provided by the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística* — IBGE, 2016; 2018), through the IBGE Automatic Recovery System (*Sistema IBGE de Recuperação Automática* – SIDRA).

Table 1 – Soil and crop parameters used for soybean, cotton, and corn crops in western Bahia.

Parameters	Soybean	Cotton	Corn
Available Water Capacity - AWC (mm)	50	50	50
Maximum precipitation infiltration rate (mm day $^{-1}$)	35	35	35
Sowing	15/Oct	15/Nov	15/Oct
Harvest	February	May	February
Initial Kc/Average Kc/Final Kc	0.4/1.15/0.5	0.35/1.2/0.6	0.3/1.2/0.5
Vegetative period (days)	20/30/60/25	30/50/55/45	20/30/55/35
Max root depth (m)	1.3	1.7	1.7
Water fraction available for ETc = 5mm day $^{-1}$	0.5	0.65	0.55
Response coefficient yield/ productivity	0.85	0.85	1.25
Crop height (cm)	100	130	200

Source: CONAB (2017); FAO in ALLEN *et al.* (2006); Gonçalves e Libardi (2013); Maluf *et al.* (2004).

Calculation of the Water Footprint of crops

The WF calculation for soybean, cotton, and corn crops produced in the western region of the state of Bahia was carried out for the period from 2012 to 2017, according to the methodology of Hoekstra *et al.* (2011) (Equation 1):

$$WF = WF_{green} + WF_{blue} + WF_{grey} \quad (1)$$

Where: WF corresponds to Water Footprint ($m^3\ t^{-1}$); WF_{green}, Green Water Footprint ($m^3\ t^{-1}$); WF_{blue}, Blue Water Footprint ($m^3\ t^{-1}$); and WF_{grey}, Grey Water Footprint ($m^3\ t^{-1}$).

Green and blue water footprint of crops

Considering the crop development cycle, the green and blue components of the WF were calculated by Equations 2 and 3.

$$WF_{green} = \frac{CWU_{green}}{Y} \quad (2)$$

Where: CWU_{green} equals the green component of crop water use ($m^3\ ha^{-1}$); and Y equals crop yield ($t\ ha^{-1}$).

$$WF_{blue} = \frac{CWU_{blue}}{Y} \quad (3)$$

Where: CWU_{blue} equals the blue component of crop water use ($m^3\ ha^{-1}$).

The use of green water by the crop represents the total evapotranspirated rainwater from the crop during the development period, while the use of blue water relates to surface or groundwater that evaporates or is added to the product usually by irrigation (HOEKSTRA *et al.*, 2011).

In case WF_{green} is insufficient, the use of an irrigation process is considered. The water required for irrigation or blue water is determined by the difference between the water requirement by the crops and WF_{green} (BULSINK *et al.*, 2010).

The green and blue components of the crop water use (CWU) were calculated based on the accumulated daily evapotranspiration during the complete growing period of each crop (Equations 4 and 5):

$$CWU_{green} = 10\sum_{d=1}^{cgp} ET_{green} \quad (4)$$

Where: ET_{green} corresponds to evapotranspiration of green water (mm day^{-1}); d, to the sowing day; and cgp, to the duration of the crop complete growing period in days.

$$CWU_{blue} = 10\sum_{d=1}^{cgp} ET_{blue} \quad (5)$$

Where: ET_{blue} equals the evapotranspiration of blue water (mm dia^{-1}).

In order to convert water depth from millimeters into water volume in area unit ($m^3\ ha^{-1}$), on Equations 4 and 5, the value 10 was used as a multiplication factor, as recommended by Hoekstra *et al.* (2011).

To calculate Green (ET_{green}) and Blue (ET_{blue}) water evapotranspiration, the reference Evapotranspiration (ET_0) estimated by the FAO Penman-Monteith method (ALLEN *et al.*, 2006) was used, using the CROPWAT 8.0 computer program (FAO, 2010), based on 10-day intervals throughout the growth period.

The precipitation used for the calculation of ET_{green} and ET_{blue} was the effective precipitation, which corresponds to the portion of the natural precipitation available to meet the evapotranspirative demand of the crop, calculated by CROPWAT using the method of the United States Department of Agriculture's Soil Conservation Service (USDA-SCS), according to Hoekstra *et al.* (2011).

The green ET was calculated by Equation 6, being the minimum between the values of total crop evapotranspiration (ET_c) and effective precipitation (P_{efet}):

$$ET_{green} = \min(ET_c, P_{efet}) \quad (6)$$

For ET_{blue}, Equation 7 was used, being zero when the effective precipitation is greater than the crop ET:

$$ET_{blue} = \max(0, ET_c - P_{efet}) \quad (7)$$

Where: P_{efet} corresponds to the effective precipitation (mm); and ET_c, to the ET of culture water (mm day^{-1}).

Grey water footprint of crops

The grey WF component of growth of each culture was calculated by Equation 8:

$$WF_{grey} = \frac{(\alpha\, AR)/(c_{max} - c_{nat})}{Y} \quad (8)$$

Where: α corresponds to the leaching-run-off fraction (t year^{-1}); AR to the chemical application rate to the field per hectare (kg ha^{-1}), in this study the nitrogen fertilizer; c_{max} to the maximum acceptable concentration (kg m^{-3}); and c_{nat} to the natural concentration of the nutrient (nitrogen) in the receiving water body (kg m^{-3}).

The natural concentration in a receiving body of water corresponds to the concentration that would occur if there were no human interventions in the hydrographic basin. For substances of human origin that do not naturally occur in water, $c_{nat} = 0$. When natural concentrations are not known with precision, but are considered low, $c_{nat} = 0$ can be considered for simplification. However, this will result in an underestimated gray WF, when c_{nat} is not really equal to zero (HOEKSTRA *et al.*, 2011).

As pointed out in Chapagain *et al.* (2006), Hoekstra *et al.* (2009), and Lourente *et al.* (2007), nitrogen is the largest fertilizer used in soybean, cotton, and corn cultivation, and its field application values are equivalent to 50 kg ha^{-1} for soybean (EMBRAPA, 2000), 100 kg ha^{-1} for cotton (STEDUTO *et al.*, 2012), and 60 kg ha^{-1} for corn (COELHO, 2006).

Although phosphorus has a much greater environmental impact on aquatic ecosystems, due to eutrophication, these crops use less phosphorus fertilizers (CHAPAGAIN *et al.*, 2006; HOEKSTRA *et al.*, 2009 and LOURENTE *et al.*, 2007), so it was not considered for grey WF (HOEKSTRA *et al.*, 2011).

In addition, according to Hoekstra *et al.* (2011, p. 38) "it is necessary to count only the most critical pollutant, which is the one that generates the largest volume of water after the calculation above", according to Equation 8. For the leaching/runoff fraction value and natural nitrogen concentration, the values recommended by Hoekstra *et al.* (2011) were used, being 10% for nitrogen fertilizers, while c_{nat} was zero.

For the maximum acceptable concentration of nitrogen in water bodies, the values determined in CONAMA (2005) were regarded, which provides for the classification of water bodies and environmental guidelines for their framing, as well as establishes the conditions and standards of effluents discharge, presenting the value of 10 mg L^{-1}.

RESULTS AND DISCUSSION

Table 2 shows the values of the Green, Blue, and Grey components of the WF of soybean, cotton, and corn crops produced in the western region of the state of Bahia, from 2012 to 2017.

According to the values in Table 2, the green WF component presented higher values than the blue and grey ones, considering that most of these commodities crops in western Bahia are under the rainfed system, which consists in planting in periods with higher rainfall indices, thus justifying the greater use of rainwater.

Among the analyzed crops, it was observed that soybean presented higher values for the green WF component, followed by cotton and corn. Taking into account the productivity when calculating the green WF component (Equation 2), the values vary according to the crop yield. As soybean had the lowest yield during the study period, its green WF was high, unlike corn, which had higher yield and low green WF component.

According to Table 2, the crop that obtained the highest blue WF component was cotton, and several characteristics account for this behavior, such as: the duration of its cycle (sowing to harvest) is longer than that of soybean and corn; the water demand of the crop during its development cycle is higher; the time of planting; plant nutrition; and the intrinsic characteristics of each crop (root depth, leaf area, leaf architecture, vegetation cover, height, among others) (ALLEN *et al.*, 2006).

Crop yield will also influence the blue WF component and, in this case, it once again favored corn, as this crop has the highest yield over soybean and cotton. The reason for these variations is explained by the productive efficiency of corn. According to IBGE (2018), corn productivity is on average three times higher than soybean and almost 2.5 times higher than cotton.

Comparing production at the beginning of the agricultural expansion, from 1985 to 2016, soybean crops increased from 7.53 x 10^4 to 3.2 x 10^6 tons. Cotton grew in this period, jumping from 866 to 8.645 x 10^5 tons, while corn increased from 4.83 x10^4 tons in 1985 to 1.2 x10^6 tons, in 2016 (IBGE, 2016).

This increase in the production of soybean, cotton, and corn crops was higher than that registered by national production. Within the state of Bahia, the West region is currently responsible for 99.6% of soybeans; 98.4% of cotton; and 81.3% of the corn produced, which, for the most part, is exported (IBGE, 2016).

A determining factor for the high productivity of corn is that, physiologically, it belongs to the group of sugar producing plants (*Zea mays*), thus, more energy. These plants have efficient photosynthetic metabolism, type C4, characterized by minimizing photorespiration, thus becoming more adaptable to warm and sunny environments such as the western region of the state of Bahia, increasing their productive potential. Soybean and cotton are crops with C3 photosynthetic metabolism, presenting high photorespiration rate and low primary productivity, as oilseeds use approximately 2.5 times more energy for oil production, compared to sugar producing plants (BELTRÃO & OLIVEIRA, 2008).

Table 2 – Water footprint in the western region of the state of Bahia.

Year	Green component (m^3 t^{-1})			Blue component (m^3 t^{-1})			Grey component (m^3 t^{-1})		
	Soy	Cotton	Corn	Soy	Cotton	Corn	Soy	Cotton	Corn
2012	1,592.6	1,457.0	555.6	291.0	562.3	108.6	167.3	299.7	69.8
2013	1,811.4	1,187.7	583.1	331.0	458.4	114.0	190.2	244.3	73.3
2014	1,483.8	1,004.0	434.0	271.1	387.5	84.8	155.8	206.5	54.5
2015	1,301.9	1,049.3	420.3	237.9	404.9	82.1	136.7	215.9	52.8
2016	1,614.4	1,125.2	339.1	295.0	434.2	66.3	169.5	231.5	42.6
2017	1,482.8	1,140.1	639.7	271.0	440.0	125.0	155.7	234.5	80.4
Average	**1,547.8**	**1,160.5**	**495.3**	**282.8**	**447.9**	**96.8**	**162.5**	**238.7**	**62.2**
Std dev	**170.1**	**159.5**	**114.9**	**31.1**	**61.5**	**22.5**	**17.9**	**32.8**	**14.4**

Source: elaborated by the authors.

The grey component of WF had the lowest value when compared to the green and blue components of the studied commodities. The factors that most influenced the differentiation of the grey component between crops were the rate of field agrochemical application (AR) and crop yield. Cotton has the highest AR (100 kg ha^{-1}) and therefore the largest grey component of WF.

Cotton is a crop susceptible to complex insect attacks that can cause significant reduction in yield. To prevent loss or minimize damage, chemical control is used as a corrective and preventive action. However, the systematic use of this control, in addition to leading to high monetary expenditures, incurs a high risk to man and the environment, due to the possibility of its toxicity affecting unwanted targets (MIRANDA, 2010).

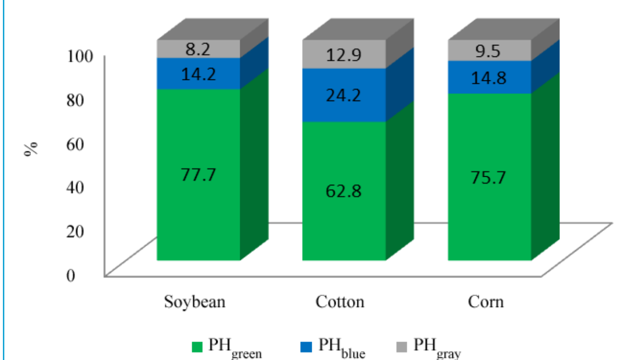
Corn has a higher AR (60 kg ha^{-1}) than soybean (50 kg ha^{-1}), but its grey component was lower than that of soybean, which can be explained, once again, by the high corn yield.

Intensive cultivation of the commodities in question can cause pollution of water resources, limiting the availability of water for other uses due to impacts that alter water quality with fertilizers and pesticides.

Pollution of water bodies affects not only the balance of receiving ecosystems, but also of other downstream users, limiting access to water resources and increasing costs for their treatment. For this reason, the correct use of inputs such as fertilizers and pesticides is necessary to reduce grey WF.

According to Cunha, Pinheiro and Vilar (2016), the pollution of water bodies through agrochemicals affects not only the balance of the receiving ecosystems due to their bioaccumulation capacity, but also from other users downstream, contributing to the reduction of biodiversity and presenting difficulty in resilience to sudden changes to the elements that integrate the environmental dynamics. The presence of agrochemicals in water can also cause difficulties for water treatment due to the possible need for more complex technologies than those normally used for potabilization (FERNANDES NETO & SARCINELLI, 2009). For this reason, the correct use of inputs such as fertilizers and pesticides is necessary in order to reduce grey WF.

To ensure the sustainability of agricultural production systems that use fertilizers and agrochemicals, it is essential to monitor and regularly assess the impacts of the use of these substances, in order to establish an acceptable level of safety for the environment (OLIVEIRA, 2005). Figure 2 shows the percentage of green, blue, and grey components of soybean, cotton, and corn WF produced in the western region of the state of Bahia, demonstrating the demand behavior of each water type in different crops.



Source: elaborated by the authors.

Figure 2 – Percentage of green, blue, and gray components of the water footprint of soy, cotton, and corn crops grown in the western region of the state of Bahia.

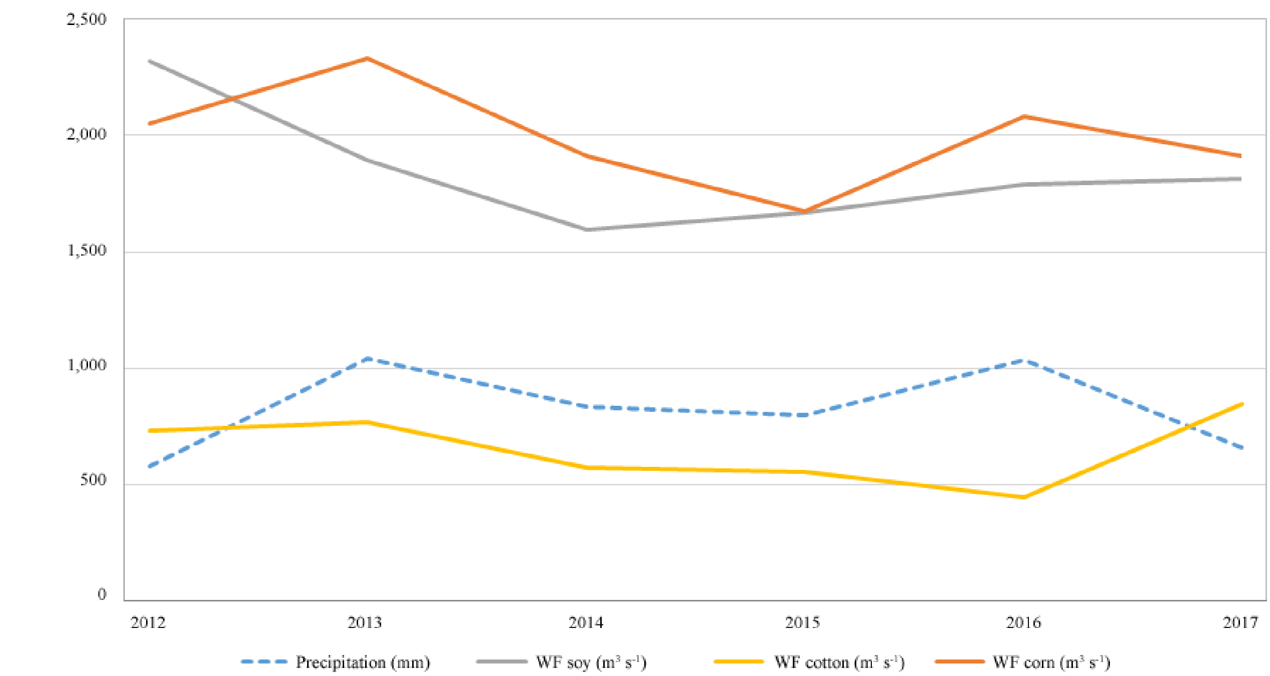
Figure 2 shows that the largest source of water for crop development is green water, which is defined as rainwater, considering it does not drain off. The crop that demanded the largest percentage of green water is soybean (77.7%), followed by corn (75.7%), and cotton (62.8%). The Green WF presented the highest percentage due, among other factors, to favorable climate conditions in the region, with adequate rainfall for the development of the crops.

As for blue water, which is groundwater and surface water (rivers, lakes, and reservoirs) incorporated into the production process via capillary rise or irrigation, the crop with the highest demand as a percentage of the total water used by the own culture is cotton, with 24.2%; followed by corn with 14.8%; and soybean with 14.2%.

Changes in the percentage of use of blue water flows can be minimized as the investment in technology appropriate to each situation and region, which can increase productivity with minimal risk to the environment; precision irrigation system; adoption of the water reuse system; the granting of the right to use water resources, using a flow and use control system; charging for water use; genetic improvement of plant species (CANDIDO, VIEIRA & SILVA, 2018).

The grey WF, which corresponds to the fresh water needed to assimilate the pollutant load, had the smallest contribution to the total value, being higher in cotton cultivation (12.9%), followed by corn (9.5%), and soybean (8.1%).

The relationship between precipitation and WF of soy, cotton, and corn is shown in Figure 3. In it, it can be seen that the precipitation line and the WF



WF: water footprint. Source: elaborated by the authors.

Figure 3 – Relationship between precipitation and water footprints of soy, cotton, and corn in the western region of the state of Bahia.

of soybean are equivalent. In the year of higher precipitation, the WF of the soybean was high and in the years of lower rainfall, the soybean showed lower WF. This justifies the green WF of soybeans to have a higher percentage in relation to total WF.

Cotton had the highest WF in the year with the lowest rainfall (2012), due to the fact that cotton requires even more blue water for its development. Corn, in turn, remained constant with precipitation in the years 2013, 2014, and 2015; however, in 2012 and 2017 when precipitation was low, its WF was high and in 2016, with high precipitation, its WF decreased.

The WF, which is the sum of the green, blue, and grey components of soybean, cotton, and corn crops produced in the western region of the state of Bahia, between 2012 and 2017, is presented in Table 3.

As shown in Table 3, the WF of soybean, cotton, and corn crops averaged, respectively, 1,993.2, 1,847.1; and 654.3 $m^3 t^{-1}$. Soybean was the crop with the highest WF between 2013 and 2017. Cotton showed the highest WF in 2012, and in 2015 its value was very close to that of soybean. Corn, in turn, showed, in all the years of the study, the lowest WF compared to soybean and cotton.

The justification for corn WF to be smaller is that this crop has higher productivity in relation to soybeans and cotton. The reason for these variations is explained by the productive efficiency of corn. According to IBGE (2018), corn productivity is, on average, three times higher than that of soybeans and almost 2.5 times higher than that of cotton.

Comparing the average WF values of the crops used in the study with those obtained in other studies, it was found that Mekonnen and Hoekstra (2014) found a global average WF of 2,107 $m^3 t^{-1}$ for soybean, while Huang *et al.* (2012) obtained a value of 1,816 $m^3 t^{-1}$ when studying soybean crop in Beijing.

Table 3 – Water footprint in the western region of the state of Bahia.

Year	Water Footprint ($m^3 t^{-1}$)		
	Soy	Cotton	Corn
2012	2,050.9	2,319.0	734.1
2013	2,332.7	1,890.4	770.4
2014	1,910.8	1,598.0	573.3
2015	1,676.5	1,670.1	555.3
2016	2,079.0	1,790.8	447.9
2017	1,909.5	1,814.6	845.1
Average	**1,993.2**	**1,847.1**	**654.3**

Source: elaborated by the authors.

Bleninger and Kotsuka (2015), however, conducted a study in Brazil and obtained a value of 2,210 $m^3 t^{-1}$ for soybean grown in Maringá, Paraná. Therefore, it was found that by analyzing the values obtained for the WF of soybean in international and national studies, the values obtained are consistent with the average values found in this study (1,993.2 $m^3 t^{-1}$).

For cotton, the west of Bahia obtained an average WF of 1,847.1 $m^3 t^{-1}$, below the global average obtained by Mekonnen and Hoekstra (2014) of 2,517 $m^3 t^{-1}$ in 2011 and 3,589 $m^3 t^{-1}$ in 2014. In a research conducted by Chapagain *et al.* (2006), the authors found for the United States a WF of 2,249 $m^3 t^{-1}$, while in Argentina it was 7,700 $m^3 t^{-1}$, and in India 8,662 $m^3 t^{-1}$, which demonstrates that this value can be quite variable according to the region.

The different WF in different regions are due to the edaphoclimatic characteristics of the place that will affect the growth of the culture; geographical inequalities; agricultural technologies used for efficient water use; agricultural productivity; and the availability of fresh water.

For corn crops, Chapagain and Hoekstra (2004) obtained 489 m^3 t^{-1} in the United States, 801 m^3 t^{-1} in China, 501 m^3 t^{-1} in Italy, and 1,937 m^3 t^{-1} in India. Mekonnen and Hoekstra (2011) obtained the value of 1,222 m^3 t^{-1} and, in a subsequent study (MEKONNEN & HOEKSTRA, 2014), the same authors obtained the value of 1,028 m^3 t^{-1} on global scale, above the WF of corn in the western region of Bahia, which corresponded to 654.3 m^3 t^{-1}.

The WF values of soybean, cotton, and corn crops produced in western Bahia, compared to studies conducted in different parts of the world, showed the importance of obtaining the WF values for each location, since the edaphoclimatic characteristics vary spatially, and production capacity depends on the availability of technology in the region.

Estimates of the WF components (blue, green, and gray) highlight the importance of adequate precipitation and distribution; control of abstraction; and the reduction of water resources pollution in the production of agricultural commodities, also favor the elucidation of the conditions for allocation or trade-off of environmental flows and their respective degree of sustainability (Hoff *et al*., 2010).

In addition, through awareness of water use, management in the governmental, business, and citizen context can be increasingly developed in terms of deficiencies and possibilities.

As a limitation of the study, it is worth mentioning that it was used as a reference for the application of agrochemicals in crops parameters already disclosed in the literature, whose values, however, may differ according to the region.

CONCLUSIONS

From the analysis of the results, it can be concluded that the average WF for the western region of the state of Bahia, between 2012 and 2017, for soybean crop corresponded to 1,972.3 m^3 t^{-1}, for cotton to 1,825.2 m^3 t^{-1}, and corn to 512.4 m^3 t^{-1}. The green component of the WF had a major contribution in western Bahia, since local climatic conditions favor crop development.

In addition, the comparison of the WF values obtained with those of other international and national regions shows that the edaphoclimatic conditions of Western Bahia are conducive to the development of soybean, cotton, and corn crops.

AUTHORS' CONTRIBUTION

Costa, M. R: Conceptualization, Investigation, Methodology, Writing — Review & Editing. Moreira, M. C.: Conceptualization, Writing — Review & Editing, Visualization, Supervision. Silva, D. D.: Writing — Review & Editing, Validation. Alencar, K. M.: Data Curation, Resources, Sofware, Formal Analysis, Methodology. Coelho, C. D.: Writing — Review & Editing.

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