Water scarcity footprint of sugarcane production in the state of São Paulo, Brazil

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Motivation and goal

Brazil is the world's largest producer of sugarcane, with an annual production of 758 million tons in 2020. This crop generated a revenue of 60.8 billion reais (R$), equivalent to 13% of the total Brazilian agriculture sector revenue in the same year (IBGE, 2022).

To make this production possible, there are four types of irrigation management for sugarcane adopted in different Brazilian regions: i) full: which aims to supply close to 100% of the water deficit (400 to 1,000 mm/year); ii) supplementary: aims to supply around 50% of the water deficit (200 to 400 mm/year); iii) fertigation: consists of the reuse of effluents from the agro-industrial process such as vinasse and residual water; and iv) salvage: the same principle as fertigation, only here the effluents from ethanol industry are diluted in low volumes of water from reservoirs (ANA, 2019; 2021). According to the Brazilian National Agency for Water and Sanitation (ANA), the volume of water used over a year in one hectare for supplementary/full irrigation is, on average, equivalent to that applied in 25 ha of fertigation/salvage.

The state of São Paulo (SP) is the major sugarcane producer in Brazil, with approximately 56% of the production volume. In 2020, the state reached a production of 431.5 million tons of sugarcane, enough to be considered the region that produced the most sugarcane in the world (IBGE, 2022). The sugarcane water demand in SP is around 311 mm of water per plant cycle, and fertigation and salvage are the predominant irrigation management for this crop in this state (ANA, 2019a; 2021). Considering the large sugarcane cultivation area in SP, this state accounts for the highest irrigation water demand in Brazil for this crop production. As a result of the water crisis that recently reached the state of São Paulo, as well as concerns about future crises due to climate change, the awareness about the damage that such events can bring to the agricultural sector has risen.

Thus, it is crucial to assess the Water Scarcity Footprint (WSF) of sugarcane in SP to support political decisions and management practices. This paper aims to analyze the WSF of sugarcane in SP, providing information on hotspots to producers and a baseline for elaborating water security policies and strategies to mitigate impacts from sugarcane production in this state.

Methods

The WSF was calculated for 1 kilogram of sugarcane produced in SP. The scope was cradle to farm gate.

The inventory of SP sugarcane production, available in the Ecoinvent 3.6 database (Folegatti Matsuura and Picoli, 2018), was updated in 2021, modifying: i) average from years 2015-2020 sugarcane yield (CONAB, 2021a); ii) area percentages occupied by 1-year cropping cycle, 1.5-years cropping cycle, and renovation (CONAB, 2019); iii) area percentages for mechanized harvest (CONAB, 2020); iv) agrochemicals consumption (Agrianual, 2020); v) consumption of agro-industrial residues: vinasse – estimated based on volumes of ethanol produced (CONAB, 2021b)– and filter cake – estimated based on the amount of sugarcane processed (CONAB, 2021a); vi) irrigation water demand, obtained from the Brazilian National Agency for Water and Sanitation (ANA) database (direct communication). Regarding irrigation efficiency, the ANA based its calculation on the technical coefficients of water use for irrigated agriculture (ANA, 2019b).

The Brazilian states and countries that produced or exported at least 60% of the inputs consumed in sugarcane production were identified through research in the official Brazilian databases (Table 1). This procedure was carried out to make possible the subsequent attribution of characterization factors (CF) for each region and calculate the WSF of the inputs. It was assumed that the whole production chain of each material was located in the same region.

Input	Participation of regions in production
Glyphosate	64% - China, 36% - USA
Gypsum	100% - Pernambuco/Brazil
Limestone	100% - Minas Gerais/Brazil
Packaging for fertilizers	53% - Minas Gerais/Brazil, 25% - Canada, 21% - Russia
Packaging for pesticides	63% - SP/Brazil, 20% - China, 17% - India
Pesticide unspecified	63% - SP/Brazil, 20% - China, 17% - India
Phosphate fertilizer (P_2O_5)	58% - Morocco, 18% - China, 15% - Mato Grosso/Brazil, 9% - Rio Grande do Sul/Brazil
Potassium fertilizer (K_2O)	69% - Canada, 31% - Belarus
Nitrogen fertilizer (N)	65% - Russia, 16% - Qatar, 7% - Algeria, 6% - China, 6% - Mato Grosso/Brazil
Diesel B10	100% - Brazil

Table 1. Origin of sugarcane inputs (percentage of consumption and main producing countries and states).

For inputs from national regions, the SIDRA database was used (IBGE, 2021) for calculating input production (kg/year) of the last three or five years available in the historical series (most recent year: 2018). Regarding imports by country and total, the COMEXSTAT database was used (MDIC, 2021) to calculate the average of the last five years available (2015-2019) for each input.

Water consumption was compiled and grouped into three parts: i) water consumption in the supply chain of each crop input; ii) other water consumption in sugarcane production (water for diluting pesticides in spraying); and iii) consumption of water for sugarcane irrigation. Water consumption for i) was calculated from the balance between the volumes of water withdrawn and returned to the ecosystem. The water consumption for spraying (200 L/ha) was calculated based on expert estimates. It is noteworthy that for cases i) and ii), the final value of water consumption refers to the water volume used in the input chain to produce one kilogram of sugarcane.

Regarding the computation of water consumed in case iii (crop production), monthly values for sugarcane irrigation (salvage) for the municipalities were obtained through formal communication with ANA. In the municipalities where there was no salvage irrigation, the consumption of freshwater (blue water) from a source for irrigation was zero, and, with this, it was understood that only fertigation with vinasse from ethanol production (reuse water), filter cake and ash (residues from the ethanol plant) were applied.
The water scarcity footprint was calculated by multiplying water consumption by the CF of the corresponding region where crop inputs were produced, and sugarcane was cultivated. Monthly and annual CFs of the AWARE model (Boulay et al., 2018) were used and, for reasons of sensitivity, the monthly and annual CFs of this model regionalization for Brazil (AWAREBR) (Andrade et al., 2019). The WSF value of irrigation water at sugarcane farms was calculated using the weighted sum of the monthly WSFs per municipality in relation to the sugarcane production in each municipality. Data regarding sugarcane production at the municipality level was from IBGE (2022).

Results and discussion

The results showed that about 95% (1.29E-04 m³/kg sugarcane) of the total water consumed in sugarcane production came from the supply chain, especially from nitrogen fertilizer production. Water for dilution of pesticides in spraying corresponded to 3% (4.2E-06 m3/kg) of the total water consumed in the sugarcane chain, while irrigation contributed to only 2% (3.2E-06 m3/kg) (Figure 1a).

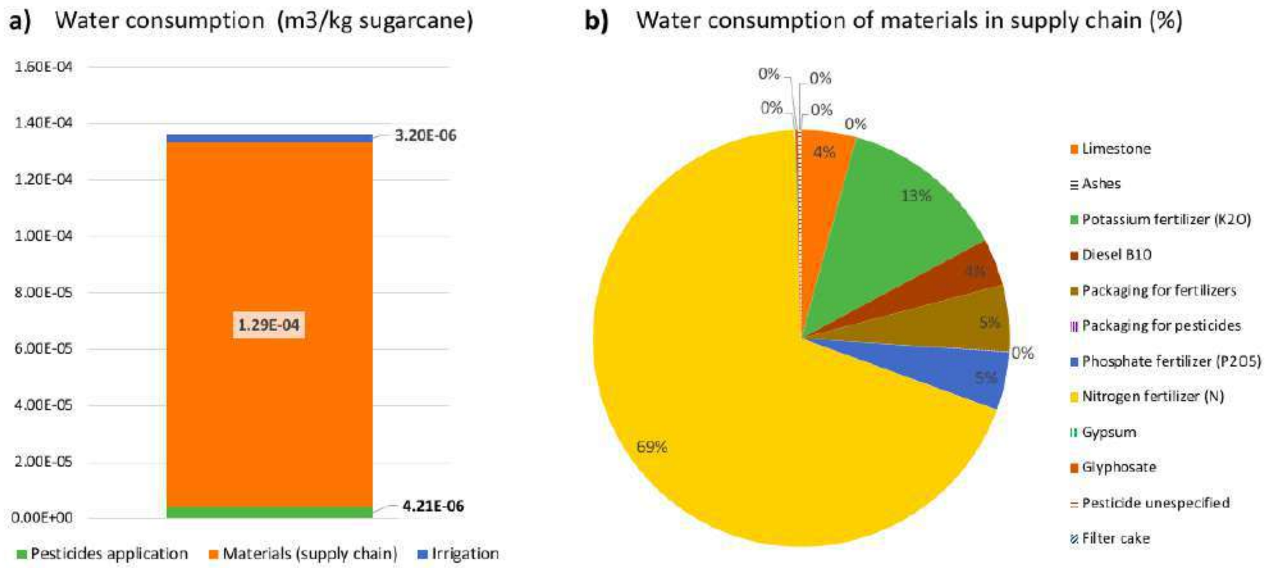

Figure 1. a) Water consumption in sugarcane production in São Paulo (m³/kg); b) Water consumption of inputs used in the sugarcane production (m³/kg).

Regarding freshwater consumption for irrigation, it varied throughout the year and was concentrated in only 20 municipalities, while the remaining applied fertigation using vinasse and wastewater from the ethanol industry. It reached a maximum value of 3.95 m³/ha.month in August in the municipality of Itapura, and a minimum of zero, meaning there is no freshwater demand throughout the year in 625 municipalities (97% of the SP total).
The annual WSF (m^3/kg) of sugarcane in the state of São Paulo ranged from 2.81E-03 (AWAREBR) and 2.56E-03 (AWARE) (Figure 2a). The consumption of materials used in sugarcane production was the main responsible for this footprint (2.79E-03 with AWAREBR characterization factors and 2.55E-03 with AWARE factors). Nitrogen fertilizer accounted for 74-80% of the total impact (Figure 2b).

The WSF of sugarcane irrigation ranged from 2.09E-05 (AWAREBR factors) to 2.37E-06 (AWARE factors). The highest impact was in August, using both AWAREBR and AWARE FCs; the lowest values were in February when using the FCS AWAREBR and in March, using the FCs AWARE.

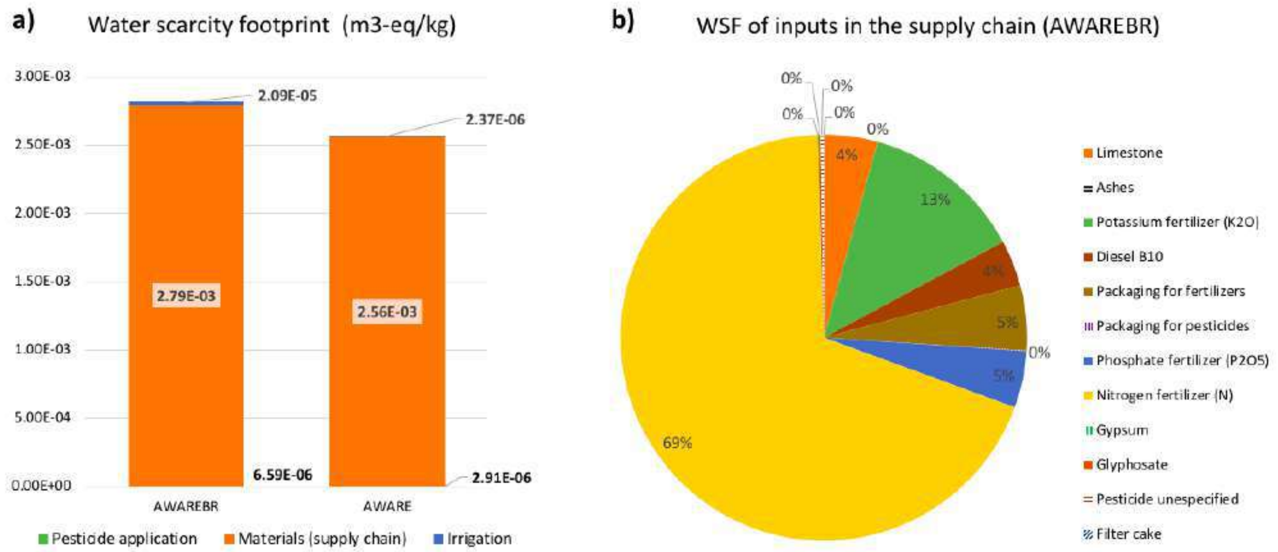

Figure 2. Water scarcity footprint of sugarcane production in São Paulo. a) overall impact (m^3/kg), considering AWARE and AWAREBR FCs; b) share of impact per material (AWAREBR)

The irrigation water consumption and, consequently, the WSF related to irrigation were due to the practices adopted by producers in the state of SP. This situation was emphasized by Dolganova et al. (2019), who pointed out that even though Brazil was responsible for 14% of all sugarcane imported by the European Union (EU), the country represented only 0.2% of the WSF of EU sugarcane imports. In comparative terms, the maximum consumption value observed in SP farms was 3.95 m^3/ha.month, while Kaemai et al. (2021) reported that sugarcane produced in Thailand (the fourth largest producer in the world) applied from 8248 to 18556 m^3/ha, depending on the region in which it was produced. In India (the world's second-largest producer), the cultivation phase had a blue water demand of 0.175 m^3/kg (Hiloidhari et al., 2021), while in SP, the consumption was 2.81E-03 m^3/kg.

Conclusions

The present study used a consistent and reproducible procedure to calculate the water scarcity footprint of sugarcane production in the state of São Paulo. This procedure can be used in other WSF studies of crops.

The highest water consumption came from the production of sugarcane inputs and the lowest from irrigation at sugarcane farms. In terms of WSF, the most significant footprint was also related to inputs supply chains, in particular nitrogen fertilizer, showing the importance of reducing this input in sugarcane production or using other sources of nitrogen to fulfil the crop needs, such as waste streams from local crop and food producers.

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