Article

# Estimation of the water footprint of sugarcane production for the mills of the Papaloapan basin

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## Abstract

In the world and in Mexico, agriculture uses approximately 75% of fresh water. The scarcity of water worldwide forces that water-saving techniques are increasingly used in the agricultural sector, since it has economic value. An important concept that helps to know the amount of water used in production and consumption is the water footprint. The objective of this research is to estimate the water footprint for the cultivation of sugarcane in the Papaloapan basin to propose measures that contribute to improving the efficiency of water use in this crop. For this research, the water footprint of the 12 sugar mills in the Papaloapan region was calculated, it was carried out following the procedure of Allen *et al*. (2006); FAO (2006); Haro *et al*. (2014). The largest water footprint is recorded in the areas that supply cane to the sugar mills of El Carmen (328 $m^3$ $t^{-1}$ of cane), San Nicolás (313 $m^3$ $t^{-1}$ of cane) and San José de Abajo (309 $m^3$), while the mill of San Pedro registered the smallest water footprint (239 $m^3$ $t^{-1}$). Per hectare, the areas that supply cane for El Carmen have the highest value with 21 301 $m^3$, followed by San Nicolás with 21 221 $m^3$ and by San Miguelito with 20 923 $m^3$. In these areas, it is possible to reduce the water footprint by better managing the crop and using varieties with more productivity.

**Keywords:** efficiency, sugarcane, water footprint, water scarcity.

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# Introduction

Water is a finite resource indispensable for life, public health, ecosystems, biodiversity, food production, hygiene, industry, energy and economic development. It has important cultural, social, religious and economic connotations that sometimes complicate its efficient use. The indiscriminate use that has been made of the resource, coupled with the lack of care to avoid contamination of surface and underground deposits, causes a type of scarcity that can cause significant limitations for its use.

At present, the appearance of the consequences of climate change that are expressed as atypical torrential rains and prolonged droughts, as well as human actions that lead to excessive pollution of surface and groundwater, force water issues to be treated with great attention by the government, the academic sector and society in general.

In this context of controversy regarding the characteristics of water, the Dublin Statement in 1992 sets out several principles. The following principle is relevant to what we want to highlight in this research: principle No. 4 water has an economic value in all its various competing uses for which it is intended and should be recognized as an economic good (WMO, 1992).

Deficiencies in water management have caused that, of the 731 hydrological basins defined in the country, 104 present availability problems (SEMARNAT, 2014). In the world, agriculture and livestock demand a little more than 70% of the total use of fresh water; various actions have led to the deterioration and contamination of water resources. By 2025, approximately 1.8 billion people worldwide are expected to face conditions of absolute water scarcity (FAO, 2013). Given this panorama, it is necessary to have increasingly efficient irrigation and supply systems in agriculture that allow the maximum possible saving of water, with the aim of ensuring the resource for future generations.

SEMARNAT (2014) mentions that, of the total freshwater in the country, 77% is destined for agriculture, 14% for urban public use and 9% for industries and thermoelectric plants, water is a resource that can be used in practically all economic activities, so its allocation should flow to the activities that make the best use of this resource.

In recent years, Mexico has made progress in some areas, such as the implementation of a legislative system through the National Waters Law (which includes the definition of water rights, their public registration and the possibility of transferring rights between users) and the creation and operation of the National Water Commission (CONAGUA, for its acronym in Spanish), but it still faces major problems in terms of sustainability, economic efficiency, equity, overexploitation, pollution, market failures and lack of regulations, to mention the most obvious, which can be encompassed in governance issues.

Given this scenario, it is necessary to have policies that contribute to the efficient management of water in general and in particular, for agricultural use. Policies that allow coordination between the different levels of management from users to authorities and that an efficient allocation of the resource is promoted, which is flexible to future climatic conditions and the resource is used in a sustainable way.

To support the improvement in the allocation of water in the various economic activities, some indicators have been constructed, among which the water footprint stands out. The study of human impacts on the environment has generated concepts such as ecological footprint, carbon footprint and more recently that of water footprint.

The objective of the research was to estimate the water footprint of sugarcane cultivation in the mills of the Papaloapan basin. It is hypothesized that sugarcane has a higher water footprint than other crops in Mexico and that not all the sites where sugarcane is planted in the study area presents the same value for the water footprint. The concept of water footprint is shown as an indicator of sustainability that allows identifying cause-and-effect relationships at the socio-environmental level, with socioeconomic activities being the main factor of pressure on water. It establishes a direct relationship between water systems and human consumption. This relationship can help determine factors that explain both water scarcity and pollution, but it can also allow for improved water use in agricultural production.

According to AGRODER (2012), the water footprint is a planning tool for water resource management, which together with other indicators provides a comprehensive view of the impact that the human population has on the environment and ecosystems. Sugarcane requires large amounts of water resources for its development, which is why and because of the concentration of this crop in the study region that the Papaloapan basin was selected, which has historically been a sugarcane area with a significant number of mills in three states of the Mexican Republic. The water footprint can be estimated for all activities in which this resource is used. Hoekstra and Mekonnen (2011) calculated the water footprint for humanity, they did it by nation from a perspective of production and consumption.

They estimated the green, blue and gray footprint. Some authors have measured the effects of interannual variability of consumption, production, trade and climate on crops and their relationship to the green and blue water footprint and virtual interregional water trade (Zhuo *et al*., 2016). Forecasts for the future have also been considered, presenting different estimates of the water footprint considering population growth, economic growth, different production/trade patterns, consumption patterns and the development of technologies (Ercin and Hoekstra, 2014).

The estimation of the water footprint has been made for several crops and with different objectives. Haro *et al*. (2014) estimated the water footprint for sugarcane grown for use in ethanol production; that is, as a source of energy and to reduce fossil fuel emissions in transport, so they analyze the impact of a policy to make ethanol from water. In livestock activities, the water footprint for the production of chicken, pork and calves in different countries and production systems has been estimated (Gerbens-Leenes *et al*., 2013). It was also calculated for the stabled cattle, (Navarrete-Molina, 2016), which was done in the Comarca Lagunera, Mexico.

When comparing some studies on the water footprint in cane cultivation in other countries, it is concluded that the water footprint is one of the most widespread, updated and used indicators to evaluate the use and consumption of water associated with a product, activity or hydrographic basin. For Brazil, the gray water footprint in the sugarcane yield was estimated and considered a high value and thus demonstrated how much this crop can demand in water resources to dilute its pollutant load (Lins *et al*., 2019).

In Argentina, a regional map of the water footprint of sugarcane cultivation was constructed (Jorrat *et al*., 2018). The water footprint has been used to know the amount of water resource that is imported or exported. One case is that estimated for Morocco by Schyns and Hoekstra (2014). In the estimation of the water footprint, alternative methodologies have been applied, there are the cases of the studies of Allen *et al*. (2006); FAO (2006); Lamastra *et al*. (2014); Haro *et al*. (2014) and those carried out with the proposal of Hoekstra *et al*. (2011).

## Materials and methods

In Mexico, 653 aquifers have been defined for groundwater management, which supply a large part of the water demands of industrial developments and about 65% of the volume of water demanded by cities where some sixty million inhabitants are concentrated. In addition, these aquifers constitute the main source of supply for the rural population and provide water for irrigation of approximately two million hectares, equivalent to 35% of the irrigated area in the country (SEMARNAT, 2013).

The Papaloapan River is the second most important hydrographic basin in Mexico, has a length of 354 km, originates at the confluence of the Valle Nacional and Santo Domingo Rivers and flows into the Gulf of Mexico in Alvarado, Veracruz. It passes through the states of Oaxaca, Puebla and Veracruz. Thanks to this length of the basin, it helps several mills to acquire their production. For this research, the calculation of the water footprint of 12 sugar mills in the Papaloapan region was carried out. The locations of these mills are as follows (Table 1).

**Table 1. Location of the mills analyzed.**

| Mill | Location |
|---|---|
| La margarita | Section of the Córdoba-Tierra Blanca railway, Veracruz, km 69 of the flag Station called Vicente, Oax. Córdoba-Veracruz highway (Federal Road 150) at the ‘La Tinaja’ junction. |
| El Refugio | El Refugio Station, belonging to the municipality of Cosolapa |
| Constancia | Tezonapa, Veracruz |
| Motzorongo | Motzorongo, belonging to the municipality of Tezonapa, Veracruz |
| El Carmen | Located in the central area of the state of Veracruz |
| La Providencia | It is located in Cerrada Constitución, Providencia, Cuichapa, Veracruz |
| San Nicolás | It is located in the state of Veracruz, Amatlan highway s/n, Congregación Gobos García, municipality of Cuichapa |
| San Cristóbal | Nicolas Bravo #5, Carlos A. Carrillo, Veracruz |
| San Pedro | Lerdo-Saltabarranca neighborhood road s/n, Lerdo de Tejada City, Veracruz |
| San José de Abajo | Known domicile s/n, main street, Locality of Ignacio Vallarta, municipality of Cuitlahuac, Veracruz |
| San Miguelito | Córdoba-Amatlán highway km 2 Col. Buena Vista, Córdoba, Veracruz |
| Tres Valles | City of Tres Valles, Veracruz |

The calculation of the water footprint for the area that supplies sugarcane to the 12 sugar mills of the Papaloapan basin was carried out following the procedure of Allen *et al*. (2006); FAO (2006); Haro *et al*. (2014). The process to determine the water footprint included several steps, which are described below: first, the sugar mills were georeferenced by taking the decimal coordinates of north latitude and west longitude from SAGARPA-SIAP-CONADESUCA (2014). The average height above sea level of the municipality was taken as the altitude of the sugar mills.

Next, the weather stations closest to the sugar mills were located. For this purpose, the decimal coordinates of the weather stations available by state on the microsite of the CLICOM system of the Center for Scientific Research and Higher Education of Ensenada, Baja California (CICESE, 2020) were taken.

When comparing the georeferencing of sugar mills and weather stations, the weather station whose decimal coordinates of latitude and longitude were equal to or very similar to those of the sugar mills was chosen. As a third step, reference evapotranspiration (ETo) was estimated as the main parameter from which the water footprint of sugarcane is quantified. The FAO reference evapotranspiration calculator was used for this calculation (Raes, 2012). The ETo calculator considerably reduces the demand for information required for ETo estimation. The minimum information required by such software are the latitude and longitude coordinates of the respective weather station, the altitude above sea level, the maximum temperature and the minimum temperature.

Meteorological data were stated to correspond to monthly data. In addition, the option that the temperature data are not tied to a specific year was selected, in addition to the fact that the data correspond to the months of January to December. The program uses the data calibrated in advance for the location, in this case, of the sugar mill. In this way, the ETo calculator will consider the location of the mill. The sugar mill will also be located in a semi-wet or wet area. The option that the area where the sugar mill is located is an area with light to medium winds is also left. The data entered in the interface correspond to the sugar mill La Margarita, located in Oaxaca.

After entering the required information in the interface, the file is created, so a new interface appears in the dialog box. In this information, one has the option of stating information about air temperature, air humidity, wind speed, sunlight and radiation.

To exemplify, the case of the mill La Margarita is shown (Table 2). The maximum temperature and minimum temperature of the San Juan Bautista Tuxtepec station are captured, with the coordinates and altitude above sea level, corresponding to the mill La Margarita, and the options that the FAO ETo calculator uses by default will provide the reference evapotranspiration (ETo) for the calculation of the water footprint of sugarcane. For example, by stating that the maximum temperature in March was 28.9 $^{o}$C and the minimum temperature was 18.3 $^{o}$C, the calculator will automatically show that the evapotranspiration for that month was 4.1 m per day. The ETo is calculated automatically when both temperatures are entered.

**Table 2. Temperature and precipitation of the mill La margarita.**

| Month | Maximum temp (ºC) | Minimum temp (ºC) | Average temp (ºC) | Precipitation (mm) | ETo (mm/day) | Kc | ETo*Kc | Days/month | Total ETo/month |
|---|---|---|---|---|---|---|---|---|---|
| January | 23.2 | 16.2 | 19.7 | 28.9 | 2.4 | 0.6 | 1.32 | 31 | 40.9 |
| February | 24.5 | 16.7 | 20.6 | 16.1 | 2.9 | 0.4 | 1.1 | 28 | 30.9 |
| March | 28.9 | 18.3 | 23.6 | 16.5 | 4.1 | 1 | 3.9 | 31 | 120.7 |
| April | 33 | 20.8 | 26.9 | 41.7 | 5.1 | 0.8 | 3.93 | 30 | 117.8 |
| May | 33.3 | 22.3 | 27.8 | 178.9 | 5 | 1.2 | 5.8 | 31 | 179.8 |
| June | 30.5 | 21.8 | 26.1 | 562.2 | 4.3 | 1.3 | 5.68 | 30 | 170.3 |
| July | 29.6 | 21.5 | 25.6 | 587.1 | 4 | 1.4 | 5.4 | 31 | 167.4 |
| August | 30.4 | 21.4 | 25.9 | 465.3 | 4.2 | 1.2 | 4.91 | 31 | 152.3 |
| September | 28.6 | 21.6 | 25.1 | 598.1 | 3.4 | 1.3 | 4.45 | 30 | 133.6 |
| October | 30.5 | 21.7 | 26.1 | 174.1 | 3.7 | 1.2 | 4.44 | 31 | 137.6 |
| November | 26.9 | 18.3 | 22.6 | 55.7 | 3 | 1.6 | 4.86 | 30 | 145.8 |
| December | 26.3 | 18.3 | 22.3 | 103 | 2.7 | 1.1 | 2.89 | 31 | 89.6 |
| | | | | 2 828 | | | | | 1 487 |

## Results and discussion

For this research, the water footprint of sugarcane grown in areas that supply the 12 sugar mills of the Papaloapan region was estimated, the methodology used by De Allen *et al*. (2006); FAO (2006); Haro *et al*. (2014), was applied, which was described in the methodology section. Given that cane crops in the basin, in general, are reported in the statistics as rainfed, and although it is known that they receive supplemental irrigations in some months of the year (two or three), the methodology used considers the value of the footprint as a green footprint and it was not possible to make the distinction for the blue footprint, even if it was minimal, nor to obtain economic estimators in relation to the productivity of irrigation water.

The results are presented in two parts: first the results obtained for the water footprint of sugarcane in the areas that supply the 12 sugar mills that continue to operate in the Papaloapan basin are shown, as well as productivity data in these areas and then, using economic data, the magnitude of said footprint is analyzed in those terms.

### Water footprint results

The results obtained of the water footprint for the cane areas of the mills analyzed register values ranging from 239 $m^3$ $t^{-1}$ to 328 $m^3$ $t^{-1}$, a difference of 89 $m^3$ $t^{-1}$, an amount that is significant (Figure 1). For the calculation of this concept, the cane yield per hectare and the annual evapotranspiration of the crop participates in an important way. The simple average for the studied area amounts to 274 $m^3$ $t^{-1}$. Mekonen and Hoekstra (2011) report a water footprint of 200 $m^3$ $t^{-1}$ for sugar crops in which they include sugarcane, while in Hoekstra and Champagne (2006), they make estimates of virtual water. In the case of Thailand, Kongboon and Sampattagul (2012) estimated a total water footprint of 202 $m^3$ $t^{-1}$, although they include the gray footprint that is not considered in this work. In the Papaloapan basin, there are higher water footprints, probably due to greater evapotranspiration in combination with slightly lower yields.

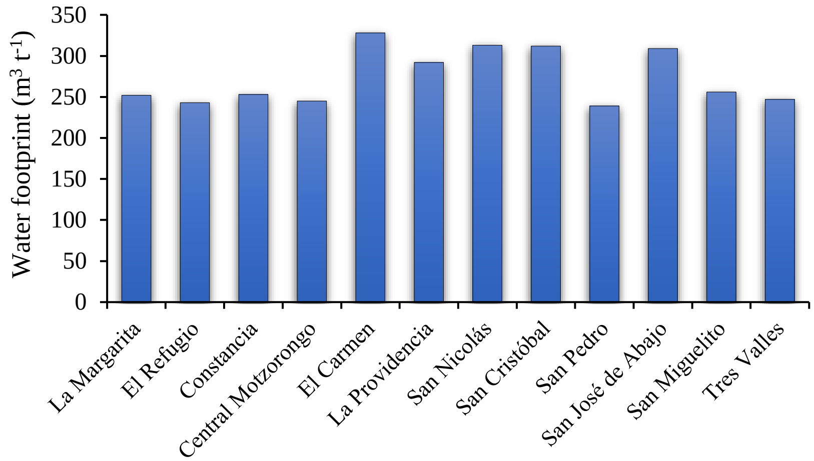


**Figure 1. Estimated water footprint in the Papaloapan River basin.**

The evapotranspiration estimate reports values of 1 487 mm and up to 2 122 mm (Figure 2), which combined with low yields has an impact, in general, on the highest values for the water footprint. In Figure 2, the mills that have the highest levels of evapotranspiration are those that register the highest levels of water footprint: El Carmen and San Nicolás.

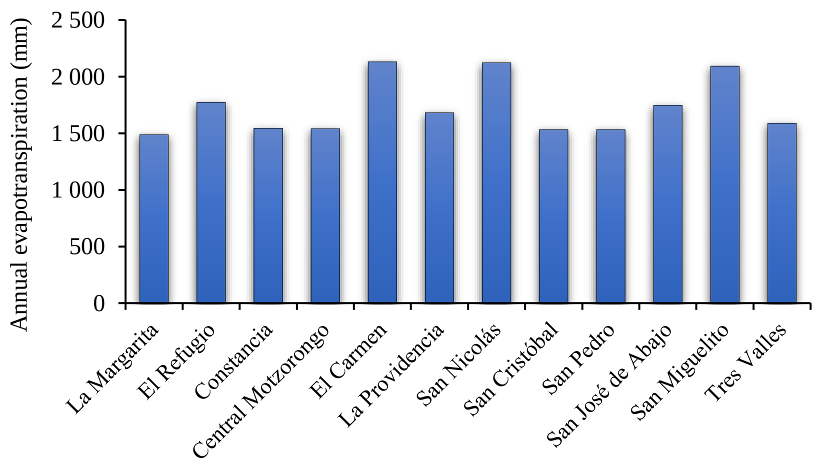


**Figure 2. Evapotranspiration**.

## Water footprint in economic terms

Given the economic and social importance of the sugar activity, since the middle of the last century, a decree was issued, so that the agricultural areas in influence of the mills were prohibited from sowing crops other than sugarcane, with the exception of activities linked to crop rotation practices.

After that, the different decrees, regulations and laws that have been approved to regulate the sugar activity have highlighted the statement of public interest of all activities related to the industry, from sowing to industrialization.

The yield per hectare is an important indicator for any crop, it also has a relevant role in the context of the calculation of the water footprint. This information is shown in Table 3, where it was observed that the areas that supply cane to the mills that have the highest yields also include the smallest areas, so it is possible that they have greater control of the production process: San Miguelito and El Refugio. While the mill El Carmen, with the smallest area, registers an intermediate yield (65 t $ha^{-1}$).

**Table 3. Yield and area of sugarcane in the area of the Papaloapan mills.**

| Mill | State | Gross milled cane (t) | Area (ha) | Yield (t $ha^{-1}$) |
|---|---|---|---|---|
| La Margarita | Oaxaca | 1 123 351 | 19 077 | 58.9 |
| El Refugio | Oaxaca | 471 423 | 6 456 | 73 |
| Constancia | Veracruz | 771 752 | 12 655 | 61 |
| Central Motzorongo | Veracruz | 1 338 219 | 21 267 | 62.9 |
| El Carmen | Veracruz | 242 071 | 3 724 | 65 |
| La Providencia | Veracruz | 864 446 | 15 005 | 57.6 |
| San Nicolás | Veracruz | 1 014 907 | 14 981 | 67.7 |
| San Cristóbal | Veracruz | 2 646 308 | 53 825 | 49.2 |
| San Pedro | Veracruz | 1 202 882 | 18 736 | 64.2 |
| San José de Abajo | Veracruz | 512 984 | 9 091 | 56.4 |
| San Miguelito | Veracruz | 485 674 | 5 931 | 81.9 |
| Tres Valles | Veracruz | 2 329 987 | 36 225 | 64.3 |

The first finding is that there are three mills that exceed 20 000 $m^3$ of footprint per hectare, more than 5 000 $m^3$ than those with the smallest values (Figure 3). Since water has a value, which in most cases can be expressed in monetary units, this indicates that a valuable resource is being lost or not used in this crop. It also says that there is an area of opportunity to improve the management of cane cultivation, using better cultivation practices, such as tillering after harvest to retain moisture, improve fertilization, carry out emergent and post-emergent control of weeds and pests, such as the borer, or using better seedling or seed to improve yield and thus reduce the water footprint that is a loss of water from the basin.

In other studies, such as that carried out in a region of Jalisco in which a value for the water footprint of 104.9 $m^3$ $t^{-1}$ was obtained, under conditions of water stress, they show a great difference (Haro *et al*., 2014). In general, the economic explanations that have to do with agricultural inputs, once the technology to be used in production has been selected, refer to the different quantities of the input in question that are optimal both from the technical point of view and from the economic point of view; that is, how much it is recommended to use the input in question so that it is economically advantageous. If the producer does not have the economic resources to acquire the recommended amount of input, this information makes it possible to know the contribution in monetary units of the last applied unit of the variable input in question; that is, the value of the marginal productivity of the input.

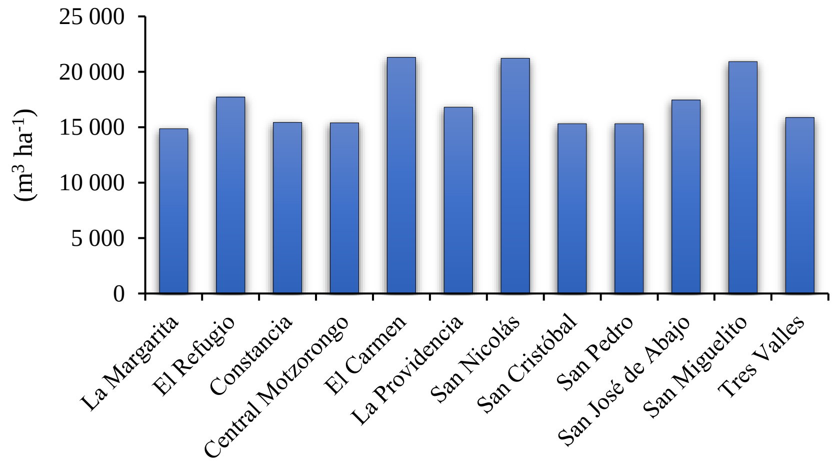


**Figure 3. Water footprint per hectare.**

In the case of the water footprint, we talk about the value expressed in monetary units, units of a resource that are lost in the process, not of what it contributes, the water footprint is an amount of water per tonne of sugarcane that is lost from the basin and that will no longer be available, for that crop, or for any other. In relation to the income per ton of cane per $m^3$ of footprint, the highest values are for La Margarita, San Cristóbal, San Pedro and La Constancia (Figure 4).

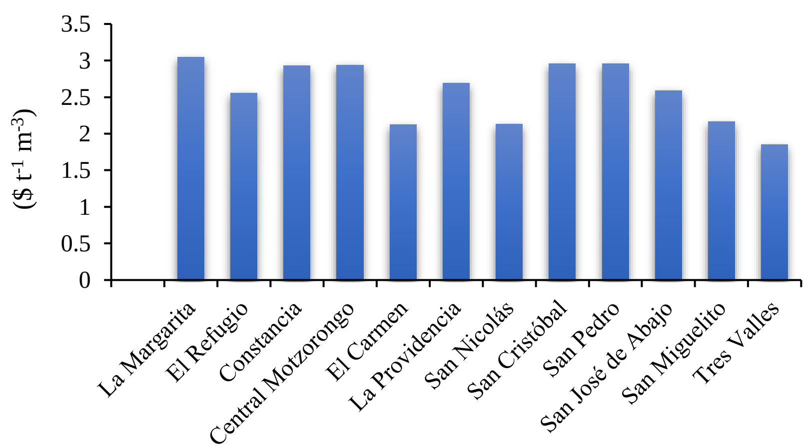


**Figure 4. Monetary estimation of the water footprint per ton.**

This magnitude was also calculated for the case of the value of production, which is expressed per hectare. It is observed that when the water footprint per hectare is expressed with respect to the value of the production, the highest values that are found in San Cristóbal and Tres Valles (Figure 5). The study did not calculate the value of water, nor its marginal productivity, but the concept of water footprint is an indicator that could give information regarding the way in which the water resource of the basin is being used and the need to improve the management of this or perhaps the use of the resource in other crops or economic activities. The information shown in Figure 5 corresponds to the monetary value of the basin water outlet in each sugarcane-producing area per hectare.

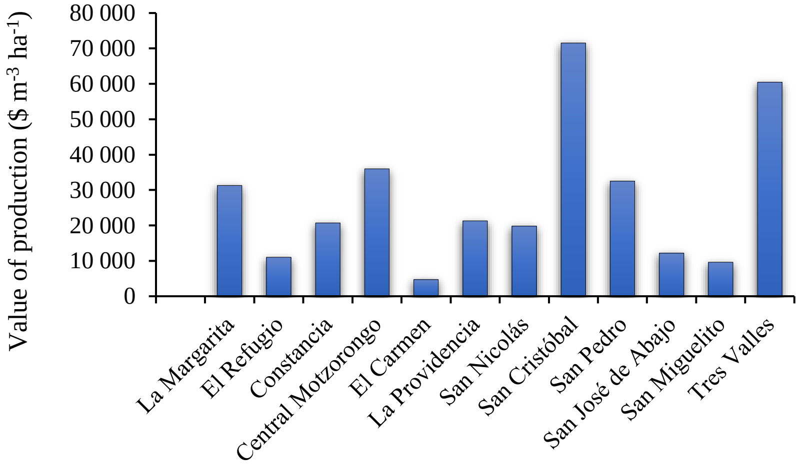


**Figure 5. Monetary estimation of the water footprint per hectare.**

## Conclusions

The water footprint of sugarcane is larger compared to other crops in the country for which data are available. In the area, there are important variations with a difference of 89 $m^3 t^{-1}$, between the minimum and maximum value, which indicates an area of opportunity. The water footprint of the sugarcane grown in the areas that supply the mills located in this basin is explained to a greater extent by evapotranspiration and yield. Then the increase in productivity opens the possibility to reduce this indicator.

Among the cultural activities that can be improved are: tillering after harvest to retain moisture, improve fertilization, carry out emergent and post-emergent control of weeds and pests such as the borer. About the water footprint in the area, it is concluded that the mills with larger areas have less control of the production processes, which is reflected in the yields. For this case, it can be said that there are diseconomies of scale.

## Cited literature

AgroDer. 2012. Huella hídrica en México en el contexto de Norteamérica. WWF México y AgroDer. DF, México.

CICESE (Centro de Investigación Científica y de Educación Superior de Ensenada). 2020. Base de datos climatológica nacional (sistema CLICOM). http://clicom-mex.cicese.mx.

Ercin, A. E. and Hoeskstra, A. Y. 2014. Water footprint scenarios for 2050: a global analysis. Environment International. 64:71-82. http://dx.doi.org/10.1016/j.envint.2013.11.019.

FAO. 2006. Evapotranspiración del cultivo, guía para la determinación de los requerimientos de agua de los cultivos. Serie de Riego y Drenaje FAO No. 56. Food and Agriculture Organization of the United Nations, Rome. 322 p.

FAO. 2013. Afrontar la escasez de agua Un marco de acción para la agricultura y la seguridad alimentaria. Informe Sobre Temas Hídricos No. 38. 97 p. http://www.fao.org/3/a-i3015s.pdf.

Gerbens-Leens, P. W. Van Lienden, A. R.; Hoeskstra, A. Y. and Van der Meer, T. H. 2012. Biofuel scenarios in a wáter perspective: the global blue and green wáter footprint of road transport in 2030. Global Environmental Change. 22:764-775. http://dx.doi.org/10.1o16/j.gloenvcha.2012.04.001.

Haro, M. E.; Navarro, I.; Thompson, R. and Jiménez, B. 2014. Estimation of the wáter footprint of sugarcane in Mexico is ethanol production an evironmentally feasible fuel option? J. Water Climate Change. 05.1:70-85. doi:102166/wcc.2013.056.

Hoekstra, A.Y. and Chapagain, A. K. 2006. Water footprints of nations: water use by people as a function of their consumption pattern. Water Resour Manage. Doi:10.1007/s11269-006-9039-x.

Hoeskstra, A. Y.; Champagain, A. K.; Aldaya, M. M. and Mekonnen, M. M. 2011. The water footprint assessment manual. Setting the Global Estándar. Water Footprint Network. 228 p.

Jorrat, M.; Araujo, P. and Mele, F. 2018. Sugarcane water footprint in the province of Tucuman, Argentina. Comparison between different management practices. J. Cleaner Produc. 188:521-529. https://doi.org/10.1016/j.jclepro.2018.03.242.

Kongboon, R. and Sampattagul, S. 2012. The water footprint of sugarcane and cassava in northern Thailand. Social and Behavioral Sciences. 40:451-460. http://doi.org/10.1016/j.sbspro.2012.03.215.

Lamastra, L.; Alina, N.; Novelli, E. and Trevisan, M. 2014. A new approach to asseessing the wáter footprint of wine: an Italian case study. Science of the total Environment. 490:48-756. https://doi.org/10.1016/j.scitotenv.2014.05.063.

Lins, R.; Maciel, A.; Toribio, B.; Paes, M. and Siqueira, J. 2019. Assessment of the gray water footprint of the pesticide mixture in a soil cultivated with sugarcane in the northern area of the State of Pernambuco, Brazil. J. Cleaner Produc. 234:925-932. https://doi.0rg./10.1016/j.jclepro.2019.06.282.

Navarrete, M. C. 2016. Impacto ambiental y económico debido a la huella hídrica y de carbono del sistema bobino de engorda en la Comarca Lagunera, México. Tesis de Maestría en Ciencias. Universidad Autónoma Chapingo (UACH). Chapingo. Estado de México.

Raes, D. 2012. The ETo calculator. Evapotranpiration from a reference surface. Reference manual. Version 3.2. Rome. 38 p.

SEMARNAT. 2014. Secretaría de Medio Ambiente y Recursos Naturales. Programa Nacional Hídrico 2014-2018. DF, México. 139 p.

Shao, G. and Halpin, P. N. 1995. Climatic controls of eastern north American coastal tree and shrub distributions. USA. J. Biogeogr. 22(6):1083-1089.

Schyns, J. F. and Hoekstra, A. Y. 2014. The water footprint in Morocco: the added value of water footprint assessment for national water policy, value of water research report series No. 67, UNESCO-IHE, Delft, the Netherlands. 106 p.

WMO (World Meteorological Organization-Geneva, CH). 1992. International conference on water and the environment: develoment issues for the 21st century, Dublin, Ireland: the Dublin statement and report of the conference. 64 p. https://www.ircwash.org/resources/international-conference-water-and-environment-development-issues-21st-century-26-31-0.

Zhuo, L.; Mekonnen, M. M. and Hoekstra, A. Y. 2016. Water footprint and virtual water trade of China: past and future, value of water research report series No. 69. UNESCO-IHE, Delft, the Netherlands. 70 p.