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Reducing the impact of irrigated crops on freshwater availability: the case of Brazilian yellow melons

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Abstract

Purpose This study quantifies freshwater consumption throughout the life cycle of Brazilian exported yellow melons and assesses the resulting impact on freshwater availability. Results are used to identify improvement options. Moreover, the study explores the further impact of variations in irrigation volume, yield, and production location.

Methods The product system boundary encompasses production of seeds, seedlings, and melon plants; melon packing; disposal of solid farm waste; and farm input and melon transportation to European ports. The primary data in the study were collected from farmers in order to quantify freshwater consumption related to packing and to production of seeds, seedlings, and melons. Open-field melon irrigation was also estimated, considering the region's climate and soil characteristics. Estimated and current water consumptions were compared in order to identify impact reduction opportunities. Sensitivity analysis was used to evaluate variations in the impact because of changes in melon field irrigation, yield, and farm location.

Results and discussion This study shows that the average impact on freshwater availability of 1 kg of exported Brazilian yellow melons is 135 l H_2O-e, with a range from 17 to 224 l H_2O-e depending on the growing season's production period. Irrigation during plant production accounts for 98 % of this impact. Current melon field water consumption in the Low Jaguaribe and Açu region is at least 39 % higher than necessary, which affects the quality of fruits and yield. The impact of melon production in other world regions on freshwater availability may range from 0.3 l H_2O-e/kg in Costa Rica to 466 l H_2O-e/kg in the USA.

Conclusions The impact of temporary crops, such as melons, on water availability should be presented in ranges, instead of as an average, since regional consumptive water and water stress variations occur in different growing season periods. Current and estimated water consumption for irrigation may also be compared in order to identify opportunities to achieve optimization and reduce water availability impact.

Keywords Consumptive water use · Impact assessment · Life cycle approach · Water efficiency · Water footprint · Water scarcity

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1 Introduction

Water scarcity occurs when the water supply does not satisfy regional demand. According to UNEP (2011), water withdrawals have tripled over the past 50 years, and a quarter of total freshwater use exceeds supplies. Although water scarcity is related to quantity and quality, scarcity often has its roots in shortages in semiarid and arid regions of the world.

Melons (*Cucumis melo* L.) are consumed worldwide, but are mainly produced in semiarid regions subject to periodic water shortages. The best climatic conditions for melon production occur when the temperature is between 20 and 30 °C, luminosity between 2,000 and 3,000 h/year, and humidity between 65 and 75 % (Silva and Costa 2003). Melon yield in these regions can be as high as 30 ton/ha (FAO 2013a). However, this yield can only be achieved with continuous irrigation. Guaranteed water access during the dry season is important for melon producers and, at the same time, essential to people living and farmers producing in these areas.

According to the FAO (2013a), melon production in 2011 occupied more than 1 million ha, mainly in the semiarid regions of Asia and America. In 2010, Brazil was the world's third largest melon exporter (in export value) with a production area of 18,861 ha. Brazil's major melon exporters are clustered in the semiarid Low Jaguaribe and Açu (LJA) region, in the northeastern states of Ceará and Rio Grande do Norte. In 2012, this region produced 99 % of the country's melon exports (Ministério do Desenvolvimento, Indústria e Comércio (MDIC) 2013). The major melon variety is the yellow melon (var. Inodorus, Naud) (Silva and Costa 2003) which mainly supplies the European market.

Currently, water scarcity affects people living in the LJA region; this is expected to accelerate due to climate-change-based temperature increases and regional rainfall reductions (Gondim et al. 2012; UN 2011). In this sense, water efficiency is a keystone to reducing competition for scarce water and sustaining regional melon production continuity.

Water is used directly to irrigate melons in open fields and to clean them in packing houses, but it is also indirectly required for farm input production (for example, seeds, seedlings, fertilizer, and pesticides). These inputs are produced inside or outside Brazil and may impact those regions' water supply.

Some studies have quantified the direct water volumes used in melon crop production (Cellura et al. 2012; Pfister et al. 2011; Mekonnen and Hoekstra 2010; Aldaya and Llamas 2009). However, to our knowledge, none of them have considered the volumes used indirectly by other processes in the melon production chain. Furthermore, they did not evaluate the regional impact on freshwater availability (IFA) or explore options for reducing it.

This study quantifies freshwater consumption throughout the life cycle of Brazilian exported yellow melons and assesses the resulting impact on freshwater availability. Results are used to identify improvement options. Moreover, the study explores the further impact of variations in irrigation volume, yield, and production location. The results of this study shed light on major processes responsible for yellow melon IFA and on impact reduction opportunities.

2 Material and methods

2.1 Definition of basic terminology

In this study, we use terminology as developed by the UNEP-SETAC life cycle initiative (Bayart et al. 2010), which distinguishes between two types of freshwater consumption: degradative consumption and consumptive water. Degradative consumption alters the water quality after use and may cause adverse impacts, such as eutrophication, toxicity (Ridoutt and Pfister 2013), and reduction in water availability (Boulay et al. 2011a, b). Consumptive water use reduces the water available in a watershed due to evaporation, evapotranspiration, and discharge in a different watershed or embodiment in a product. This study focuses on consumptive water use. The term “water consumption (WC)” in the rest of this paper refers to “use of consumptive water” unless otherwise specified.

Two methods can be distinguished to assess the impact of water consumption on freshwater availability (IFA): so-called midpoint and endpoint levels. At midpoint level, the IFA associated with water consumption usually is assessed by multiplying the water volume with a withdrawal-to-availability water ratio, in other words, a water stress index (WSI) (Berger and Finkbeiner 2010; Pfister et al. 2009; Canals et al. 2009; Frischknecht et al. 2009). At endpoint level, the IFA associated with water consumption is assessed by multiplying the water volume with a factor related to the following protection areas: human health (Pfister et al. 2009; Motoshita et al. 2011; Boulay et al. 2011b), ecosystem quality (Pfister et al. 2009), and resource depletion (Pfister et al. 2009). We evaluated the IFA associated with water consumption at midpoint level, considering that endpoint level evaluation uncertainty is higher than with the midpoint level (JRC and IES 2011).

There are several midpoint methods available to evaluate water consumption IFA (Kounina et al. 2013). Pfister et al. (2009) use an indicator common to all protection areas that has been widely used to evaluate food products (Pfister et al. 2009; Ridoutt and Pfister 2010; Page et al. 2011; Emmenegger et al. 2011; Pfister et al. 2011; De Boer et al. 2013). The WSI proposed by Pfister el al. (2009) is a function of the total annual water withdrawal over total annual water availability, adjusted to seasonal variability according to WaterGap model data. WSI is available for most countries with more than 10,000 watersheds. Recently, Pfister and Baumann (2012) developed a monthly WSI for these watersheds. The use of a monthly WSI is especially important when studying irrigated crops in regions that are periodically water stressed, as is the case with yellow melons produced in the Brazilian semiarid region and in other major exporting countries. Ridoutt and Pfister (2010, 2013) further proposed normalizing water impact assessments by dividing them with the global average WSI value of 0.602, thus relating them to the impact of 1 l of water consumed globally.

In this study, we assess yellow melon IFA, using the WSI defined by Pfister et al. (2009) and Pfister and Baumann (2012), and normalize IFA according to Ridoutt and Pfister (2010).

2.2 System boundary, functional unit, and allocation

The yellow melon system boundary encompasses local processes (seedling production, plant production, melon packing, and farm solid waste disposal), upstream on-farm input processes (farm and packing house input production and transportation), and downstream processes (transporting melons to consumer markets) (Fig. 1). Farm and packing house inputs include seeds, coconut substrate, agrochemicals, plastics, papers, diesel, electricity, cleaning materials, and water.

The functional unit adopted is 1 kg of exported yellow melon, the production of which requires 3.64 g of seedlings and 0.034 g of seeds, according to data provided by LJA region melon farmers (Figueirêdo et al. 2013).

Ninety-five percent of the melons produced in the LJA region are of high quality and mainly exported to Europe, with the remaining 5 % sold in the national market. The market price of exported melons is higher than for melons sold locally. The average exported melon value is US$0.6/kg (99 % of total revenue), whereas the value of nationally commercialized melons is US$0.1/kg (1 % of total revenue). Thus, economic allocation of inputs and outputs regarding melon packing was performed, considering that 99 % of total revenue comes from exported melons and 1 % from nationally commercialized melons.

2.3 Inventory analysis

2.3.1 Melon farming and packing house data collection

Data were collected via questionnaires and interviews with melon-producing unit managers affiliated with seed, seedling, and melon farms, and packing houses. The information covered the average input amount and solid waste generated by these units in the production period of 2010–2011. Melon farmers were asked to report the volume of irrigation water

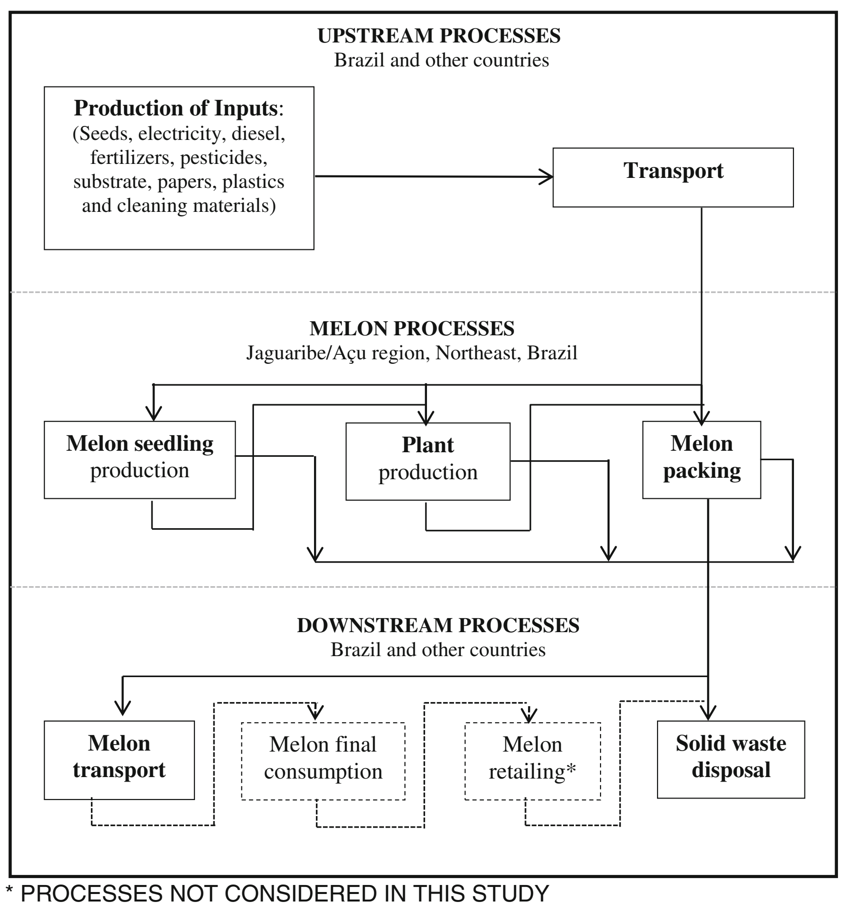

Fig. 1 System boundary of yellow melon as used in this study

applied in melon fields during each month of the mentioned production period.

Melon seeds are produced commercially outside Brazil and imported mainly from the USA (MDIC 2013). However, water consumption data for seed production were collected from an experimental 0.05-ha greenhouse at Embrapa Tropical Agroindustry in Ceará (Brazil) that can produce 1.6 million seeds per year. During seed production, water irrigates greenhouse melon plants for 65 days and then washes the seeds after they are fermented.

Seedling production uses a small amount of water for irrigation for 8 days after germination. Associated water consumption was reported by one major melon seedling producer in the LJA region with an area of 0.12 ha producing 110 million seedlings per year.

Melon seedlings are transported to farms and transplanted in open fields that are covered with plastic mulching to prevent moisturized soils from further contacting the fruits. These plants are also covered with fabrics until pollination starts to protect from pests. A drip fertirrigation system provides water during the whole production period. Harvest occurs between 65 and 70 days after seedling transplantation. On average, 1 ha in the LJA region produces 23 tons of melons. Primary data were collected at three farms and packing houses that accounted for 23 % of total 2010 melon exports.

In the packing house, harvested melons are washed, classified for either the internal and external market, and packed in corrugated paper boxes. Packed melons are trucked to the Pecém port and shipped to Rotterdam, The Netherlands, in refrigerated containers.

2.3.2 Current direct water consumption

We assumed all irrigation water informed by farmers to be consumptive, implying that losses did not return to the same watershed, which represents a worst-case scenario. We also assumed all cleaning water to be consumptive, implying that it is usually not released in the same place as the original water source (such as in soils near the production units).

2.3.3 Indirect water consumption

Melon seed and seedling production makes use of coconut substrate that is a by-product of the coconut water industry. Coconut substrate water consumption was taken from Figueirêdo et al. (2010).

Ecoinvent data were used to quantify water consumption in other melon farm and packing house input production and transport, in the transport of melons, and in solid waste disposal from seed, seedling, and melon farms, and packing houses (landfill for plastics and incineration of empty pesticides packages) (Frischknecht and Jungbluth 2007).

However, the Ecoinvent database does not distinguish between consumptive and nonconsumptive water, necessitating the following assumptions that were also adopted by De Boer et al. (2013): only 5 % of the cooling water was consumptive (Batlles et al. 2010), with 95 % assumed to return to the original water body; seawater was excluded as its availability was assumed to be unlimited, and turbine water was excluded as it is considered to be in-stream water consumption. Water extracted from lakes, rivers, wells, and unspecified sources was assumed to be consumptive.

2.3.4 Estimated water consumption for irrigation

We compared the average volume of irrigation water, as provided by farmers, with the gross irrigation water requirement (GIWR in Eq. 1a: in l/kg of melon) estimated for main LJA subregions where melon farms may be located. GIWR is computed according to FAO (1997) for the following subregions: (1) Mossoró, Baraúna, Grossos, and Tibau; (2) Aracati and Icapuí; (3) Limoeiro do Norte and Russas; and (4) Jaguaruana and Quixeré. This comparison may reveal excessive irrigation practices when the average irrigation volume is used by local farms.

GIWR represents the total irrigation volume and is calculated from the sum of irrigation water (ET_{day} in Eq. 1a: in l/ha), applied every day of the production cycle (p), divided by the melon farm yield (yield in Eq. 1a: in kilogram per hectare) times the irrigation system efficiency (System_efficiency in Eq. 1a: dimensionless).

The daily crop irrigation water (ET_{day} in Eq. 1b: l/ha) equals the crop evapotranspiration ($ET_{c.}$ in Eq. 1b: in millimeter per day) minus the effective rainfall (P_{eff} in Eq. 1b: in millimeter per day), when P_{eff} is lower than ET_c. Otherwise, ET_{day} is zero since irrigation is not required to crop development. The multiplying factor of 10,000 is used to transform millimeter in liter per hectare (1 mm=10,000 l/ha).

P_{eff} is the rainfall amount that may effectively be used by crops per day (that is, rainfall not evaporated from the soil or lost in runoff or deep percolation).

The crop evapotranspiration ($ET_{c.}$) is the day reference evaporation (ET_o in Eq. 1c: in millimeter per day) in a region multiplied by the crop coefficient (Kc_{stage} in Eq. 1c: dimensionless) of each production stage (defined for initial, development, midseason, and late season).

$$\mathrm{GIWR} = \left(\frac{\sum_{day=1}^{p} \mathrm{ET_{day}}}{\mathrm{System\_efficiency} \times \mathrm{Yield}}\right) \times \tag{1a}$$

$$\mathrm{ET_{day}} = (\mathrm{ET_c} - P_{eff}) \times 10.000, \text{ if } P_{eff} < \mathrm{ET_c} \tag{1b}$$

$$\begin{aligned} ET_{day} &= 0, \text{ if } P_{eff} \geq ET_c \\ ET_c &= ET_o \times Kc_{-}stage \end{aligned} \quad (1c)$$

The irrigation system efficiency (System_efficiency in Eq. 1a) depends on soil texture (influencing water losses from percolation and runoff) and uniformity of water application of irrigation systems. According to Vermeiren and Jobling (1986), the drip irrigation system efficiency can be estimated multiplying the soil water holding index (defined considering soil texture and crop root depth that for yellow melons is 30 cm) by irrigation uniformity coefficient, which expresses spatial variability of applied water by emitters of the irrigation system. In the LJA region, soil texture may range from sandy (soil water holding index of 0.85) to sandy–clay–loam (soil water holding index of 0.95) and the drip irrigation uniformity coefficient from 0.80 to 0.95 (Gondim et al. 2003; Miranda et al. 2008; Nunes 2006). To compare current and estimated water consumption in the LJA region, we assumed the lowest irrigation system efficiency of 0.68 (soil water holding index of 0.85 and drip irrigation uniformity coefficient of 0.80) when calculating the GIWR (Eq. 1a).

The model used by FAO to calculate the reference evapotranspiration (ETo) is Penman–Monteith that requires daily measurement of solar radiance, air humidity, air temperature, and wind speed (Allen et al. 2006). Data regarding these variables, ET_o and precipitation in melon-producing regions, were obtained from the FAO AQUASTAT database (FAO 2013b). This FAO database uses the Climate Research Unit (CRU) data (Mitchell and Jones, 2005) that are the result of global monthly observed climate variable interpolation on a 0.5°×0.5° grid, to the 1961–1990 period. CRU data are the only alternative to estimate ET_o using FAO Penman–Monteith for the 1961–1990 period in the LJA region, once there is no local meteorological station available with full datasets for this period in this region.

Effective precipitation (P_{eff}) is based on total precipitation and was estimated using the USDA SCS method available in the CROPWAT model (FAO 2010). The values of ET_o, precipitation, P_{eff}, and Kc_{stage} for the main LJA subregions and other world production regions are presented in the Electronic Supplementary Material (Tables A1 and A2).

2.3.5 Relation between irrigation and yield

According to farmers in the LJA region, melons can remain in the field for longer than 70 days because of market changes. Due to continual fertirrigation, different plots have dissimilar irrigation and productivity.

Therefore, we analyzed the effect of current irrigation on yield, correlating these two variables. One of the melon farms participating in the study provided data on irrigation and yield attained in 117 different plots for the melon growing seasons of 2010 and 2011.

2.4 Impact assessment

2.4.1 Identification of production sites

The LJA region features the following production chain processes: seedling, melon production and packing, production of coconut substrate, and solid waste disposal. Other regions are at stake for LJA region farms' input production (seeds, electricity, diesel, fertilizers, pesticides, papers, plastics, and cleaning materials). On-farm input production occurs in many Brazilian regions, as well as in other countries. Water consumed during production of these inputs is assumed to be withdrawn locally.

In order to identify these regions, we asked farmers which of their inputs were imported and which were produced in Brazil. Pesticides and cleaning materials are obtained from the national market; their production areas were identified by analyzing the Brazilian states' revenues available at IBGE (2010). Fertilizers, plastics, papers, and seeds are usually imported. We assumed that their production takes place in countries exporting these inputs to Brazil, according to information available at The Integrated System of Foreign Trade database (MDIC 2013). Since about 93 % of the electricity and about 82 % of the diesel used in Brazil are produced nationally (EPE 2011), we assumed that total production takes place in Brazil.

2.4.2 Computation of impact on water availability

To compute the IFA for the life cycle of yellow melons (measured in Eq. 2a in l H_2O-e/kg of exported melon), we first summed the IFA of each unit process (IFA_{life_cycle} in Eq. 2b: in l H_2O-e/kg of exported melon) and then normalized this ratio by dividing it by the global average water stress index (WSI_{global} in Eq. 2b: dimensionless). WSI_{global} is 0.602 (Ridoutt and Pfister 2010).

The IFA of a unit process ($IFA_{process}$ in Eq. 2b: in l H_2O-e/kg of exported melon) was computed by first multiplying the consumptive water volume demanded by a process ($WC_{process}$ in Eq. 2c: in l/kg of exported melons) by the water stress index for the given process ($WSI_{process}$ in Eq. 2c: dimensionless).

For melon plant production, the consumptive water ($WC_{process}$) used to irrigate melons and the water stress index ($WSI_{process}$) vary across growing season production periods (for example, July to September, August to October). In this case, the $IFA_{process}$ was the average of the impacts calculated to each growing season production period.

$$\mathrm{IFA} = \mathrm{IFA}_{\mathrm{life\_cycle}} / \mathrm{WSI}_{\mathrm{global}} \tag{2a}$$

$$\mathrm{IFA}_{\mathrm{life\_cycle}} = \sum\nolimits_{\mathrm{process}=1}^{n} \mathrm{IFA}_{\mathrm{process}} \tag{2b}$$

$$\mathrm{IFA}_{\mathrm{process}} = \mathrm{WC}_{\mathrm{process}} \times \mathrm{WSI}_{\mathrm{process}} \tag{2c}$$

In order to assess a process's water stress index ($\mathrm{WSI}_{\mathrm{process}}$ in Eq. 2c: dimensionless), two procedures were adopted. For melon plant production, we calculated the average of monthly water stress index ($\mathrm{WSI}_{\mathrm{process}}$ in Eq. 3a: dimensionless) for each production period according to Pfister and Baumann (2012), considering the location and duration of melon production in the growing season (Table A3 in the Electronic Supplementary Material). For all other unit processes, we used the annual WSI (Pfister et al. 2009) of a specific production region ($\mathrm{WSI}_{\mathrm{annual}}$ in Eq. 3b: dimensionless) and multiplied it by the share of that region in the production of an input ($\mathrm{Prod\_share}_{\mathrm{process,\ region}}$ in Eq. 3b: in percent). Next we added the production share of all regions where a material is produced.

$$\text{For plant production}: \mathrm{WSI}_{\mathrm{process}} = \sum\nolimits_{\mathrm{month}=1}^{n} \mathrm{WSI}_{\mathrm{month}} / n \tag{3a}$$

$$\text{For other processes}: \mathrm{WSI}_{\mathrm{process}} = \sum\nolimits_{\mathrm{region}=1}^{m} \mathrm{WSI}_{\mathrm{annual}} \times \mathrm{Prod\_share}_{\mathrm{process,region}} \tag{3b}$$

Computing the $\mathrm{WSI}_{\mathrm{process}}$ for each yellow melon chain unit required identifying the regions where water was extracted, their share in melon production (see Section 2.4.1), and the water stress index of these regions.

2.5 Sensitivity analysis

In the reference situation, we computed the LJA region melon production IFA ($\mathrm{IFA}_{\mathrm{process}}$) using the average water consumption reported by farmers and the average WSI, considering the production cycles in a year. For the sensitivity analysis, we explored possible changes in water consumption due to variation in irrigation and the consequences for the IFA from variations in plant production field locations (Table 1).

Scenario 1 is based on current average yield (23 t/ha) and the lowest irrigation efficiency (0.68).

Considering variations on soil texture and irrigation uniformity coefficient for melon production in the LJA region (Gondim et al. 2003; Miranda et al. 2008), a better case for drip irrigation system efficiency of 0.86 (soil water holding index of 0.95 for sandy–clay–loam soil and drip irrigation uniformity coefficient of 0.90) was considered in scenarios 2 and 3. In scenario 2, the average observed yield (23 t/ha) and a better irrigation efficiency (0.86) is evaluated. In scenario 3, the best case scenario for melon production in the LJA region, the higher observed yield (40 t/ha) and irrigation efficiency (0.86) are analyzed.

Yellow melons are also cultivated in other world regions. As each region has its own climate and soil conditions and may face different water shortages, the IFA will change. To assess the melons produced in other regions, we defined four location scenarios: Nicoya, Costa Rica (scenario 4); Riverside County, California, USA (scenario 5); Ciudad Real, Spain (scenario 6); and, Lavello, Italy (scenario 7). These regions were defined according to the FAOSTAT database (FAO 2013a) and Torres and Miquel (2003).

For these regions, information about growth period, crop coefficient (Kc) for each crop development stage, and the average regional melon field yield was obtained from the literature (Table A3 in the Electronic Supplementary Material). The water consumption of melons produced in these regions was assumed to be equal to GIWR and was calculated according to Section 2.3.4.

3 Results

3.1 Water consumption and impact

WC is presented as an average value for most of the unit processes considered in this study (Table 2), except for plant production in open fields. A total water volume of 198 l is consumed in order to produce and export 1 kg of melon in the LJA region, considering all unit processes. Approximately 98 % of this volume is directly used during open-field melon production, that is, for drip irrigation of melon plants. A negligible amount of water is consumed in the other melon-related production processes (seeds, seedlings, and packing). The indirect on-farm input water consumption is also minor (1.5 %).

Melons are harvested after 70 days (production period), but can be produced during the 6-month-long growing season. The average WC in plant production ranges from 186 to 202 l/kg of melon, according to the production period, with less water used from July to September (Table 3).

The average impact of yellow melons on freshwater availability (IFA) is 135 l H_20-e/kg (Table 2). IFA is also dominated by melon plant production, although the WSI is lower in the LJA region (0.404) than in other regions in which other unit processes are located (for example, a WSI of 0.710 for fertilizer production located mainly in Chile, Portugal, and Israel). However, the IFA of yellow melon varies according to the production period used to grow melons in

Table 1 Overview of scenarios analyzed in the sensitivity analysis

	Region	Description
Reference situation	Melon production in the LJA region, Brazil	WC=water withdrawal for irrigation, informed by farmers
		Yield=23 t/ha
		WSI=0.404
Scenario 1	Melon production in the LJA region, Brazil (average yield)	WC=GIWR
		Yield=23 t/ha
		WSI=0.404
		Et_c=217.82 mm
		P_{eff}=38.84 mm
		System_efficiency=0.68
Scenario 2	Melon production in the LJA region, Brazil (average yield)	WC=GIWR
		Yield=23 t/ha
		WSI=0.404
		Et_c=217.82 mm
		P_{eff}=38.84 mm
		System_efficiency=0.86
Scenario 3	Melon production in the LJA region, Brazil (the highest yield)	WC=(GIWR)
		Yield=40 t/ha
		WSI=0.404
		Et_c=217.82 mm
		P_{eff}=38.84 mm
		System_efficiency=0.86
Scenario 4	Melon production in Nicoya, Costa Rica	WC=GIWR
		Yield=33 t/ha (average value, according to FAO 2013a)
		WSI=0.015
		ET_c=373.94 mm
		P_{eff}=245.18 mm
		System_efficiency=0.86
Scenario 5	Melon production in Riverside County, USA	WC=GIWR
		Yield=28 t/ha (average value, according to FAO 2013a)
		WSI=0.878
		ET_c=884.61 mm
		P_{eff}=32.91 mm
		System_efficiency=0.86
Scenario 6	Melon production in Ciudad Real, Spain	WC=GIWR
		Yield=32 t/ha (average value, according to FAO 2013a)
		WSI=0.810
		ET_c=292.98 mm
		P_{eff}=41.66 mm
		System_efficiency=0.86
Scenario 7	Melon production in Lavello, Italy	WC=GIWR
		Yield=24 t/ha (average value, according to FAO 2013a)
		WSI=0.829
		ET_c=183.80 mm
		P_{eff}=89.19 mm
		System_efficiency=0.86

the LJA region (from 17 to 224 l H20-e/kg in Table 3), mainly because of changes in the WSI of this region (0.05 for July–September and 0.60 for October–December).

3.2 Irrigation water efficiency in melon production

Since irrigating melons during cultivation explains most of the water consumption and occurs in a water-stressed region, this process needs to be as efficient as possible to guarantee the lowest achievable IFA. More irrigation also results in higher production costs related to electricity required for water pumps.

Irrigation efficiency in LJA region melon farms was studied by comparing average irrigation with gross irrigation (GIWR, see Section 2.3.4). This comparison was made for each of the four subregions and for different production periods during the dry season (Fig. 2).

Excessive irrigation occurs in all regions and during all production periods. Melon fields cultivated from September to November, that is, in one of the driest periods requiring more consumptive water, receive 39 % more water than necessary. In periods requiring less irrigation, that is, from December to February, up to 160 % more water is applied. Irrigation (see Fig. 2) varies monthly because of changes in the temperature and wind speed in the subregions that consequently change ETo values.

Nunes (2006) also reported the use of excessive irrigation in drip irrigation systems for banana, pumpkin, and pepper crops in the Jaguaribe-Apodi Irrigation District, located in the LJA region. The ratio of required and applied irrigation water ranged from 7 to 64 %.

The usefulness of comparing present and estimated irrigation water depends on the accuracy of information obtained from farmers and the data used to estimate GIWR for the LJA region. The three farms researched in this study accounted for 23 % of the total melon exports in 2010. One of the farmers interviewed for the study uses climate data to determine the volume of irrigation water applied in melon fields, while the other two use the same volume for the entire growing season (Table 3). However, the volume of irrigation water should vary depending on the production period because of climatic variability.

The estimation of GIWR is based on data regarding climate (effective precipitation, P_{eff}, and reference evapotranspiration, ETo), crop water requirement (crop coefficient for each development stage, Kcstage), soil (soil water holding index), and the irrigation system performance, consequence of design, maintenance, and operation (irrigation uniformity coefficient). The climatic data used rely on the CRU database (Mitchell and Jones 2005), also used by FAO AQUASTAT database (FAO 2013b). According to Lima et al. (2013), high agreement between CRU and measured monthly rainfall was observed from 20 meteorological stations in this studied

Table 2 Impact of yellow melon on freshwater availability in the reference situation by process

Processes	Main producing regions	WC (l/kg)	WC (%)	$WSI_{process}$	$IFA_{process}$ (l H_2O-e/kg)	$IFA_{process}$ (%)
Melon packing	LJA region, Brazil (Mossoró—49 %, Icapuí—23 %, Aracati—10 %, Baraúna—10 %, other municipalities—8 %)	0.15	0.1	0.404	0.06	0
Plant production	LJA region, Brazil (Mossoró—49 %, Icapuí—23 %, Aracati—10 %, Baraúna–10 %, other municipalities—8 %)	195.14	98.6	0.404	80.15	98.3
Seedling	LJA region, Brazil (Icapuí—100 %)	0.05	0.0	0.404	0.02	0.0
Seed	USA (31 %), Argentina (26 %), Italy (14 %), other regions (29 %)	0.09	0.0	0.440	0.04	0.0
Paper	China (44 %), Spain (18 %), South Africa (13 %), other countries (25 %)	0.72	0.4	0.520	0.38	0.3
Plastic	Argentina (38 %), Paraguay (12 %), USA (10 %), other countries (40 %)	0.41	0.2	0.340	0.14	0.1
Fertilizers	Chile (63 %), Portugal (15 %), Israel (10 %), others (12 %)	1.02	0.5	0.710	0.72	0.5
Pesticides	Brazil (São Paulo—47 %, Rio Grande do Sul—11 %, Bahia—10 %, other states—32 %)	0.11	0.1	0.020	0.00	0.0
Electricity (BR)	Brazil (100 %)	0.04	0.0	0.060	0.00	0.0
Diesel	Brazil (100 %)	0.03	0.0	0.060	0.00	0.0
Substrate	Brazil (Aracati (CE)—50 %, Icapuí (CE)—50 %)	0.0002	0.0	0.500	0.00	0.0
Cleaning materials	Brazil (São Paulo—83 %, Rio de Janeiro—5 %, Minas Gerais—4 %)	0.15	0.1	0.020	0.00	0.0
Total (l/kg)		197.90			81.51	
IFA (l H_2O-e/kg)					135.40	

region for the 1961–1990 period. This suggests acceptable agreement between climate variables with lower spatial variability in the tropical environment, such as temperature and reference evapotranspiration. Data regarding crop coefficient, soil, and irrigation system are from studies developed in the LJA region (Miranda and Bleicher 2001; Gondim et al. 2003; Miranda et al. 2008). The irrigation system efficiency adopted (0.68) when estimating the GIWR is very conservative and based in a worst-case scenario (sandy–clay–loam soil and very low irrigation uniformity). From these considerations, we rely on the results of GIWR.

3.3 Relation between irrigation and yield

An irrigation-versus-yield analysis for 117 plots of an LJA region melon farm shows that higher yields is achieved with less irrigation water applied per kilogram of exported melon (Fig. 3). The highest yield is achieved when the lowest irrigation volume is used, that is, 40 ton/ha when 89–123 l of H_20-e per kilogram of exported melon is used. The lowest yield is observed when the highest irrigation volume is applied (14 ton/ha for 446 l of H_20-e per kilogram).

The plot in Fig. 3 suggests that higher yields may be obtained with less irrigation per kilogram of exported melon than at the present average volume (195 l of H_20-e per kilogram of exported melon with average yield of 23 ton/ha) applied by the farmers in the LJA region. Excessive use of irrigation water per kilogram of exported melon not only results in high IFA but also may affect yield and farmers' income.

Previous studies showed that excessive irrigation after transplantation may result in coarse growth and underdeveloped flowers that reduce fruit-soluble solids content in melons and, consequently, lower the quality required by world markets (Sensoy et al. 2007; Dogan et al. 2008; Zeng et al. 2009). Insufficient irrigation may also reduce yield and

Table 3 Impact of yellow melon plant production in open fields according to the production period in the growing season at the Low Jaguaribe and Açu region, Brazil

	Jul–Sep	Aug–Oct	Sep–Nov	Oct–Dec	Nov–Jan	Dec–Feb
WC in farm A (l/kg)	182.82	188.96	221.72	219.61	224.32	232.06745
WC in farm B (l/kg)	212.49	212.49	212.49	212.49	212.49	212.49
WC in farm C (l/kg)	161.36	161.36	161.36	161.36	161.36	161.36
Average $WC_{process}$ (l/kg)	185.56	187.60	198.52	197.82	199.39	201.97
$WSI_{process}$ (l/kg)	0.05	0.14	0.38	0.67	0.59	0.60
$IFA_{process}$ (l H_2O-e/kg)	8.75	25.33	74.78	133.40	116.78	121.86
Average $IFA_{process}$ (l H_2O-e/kg)	80.15					

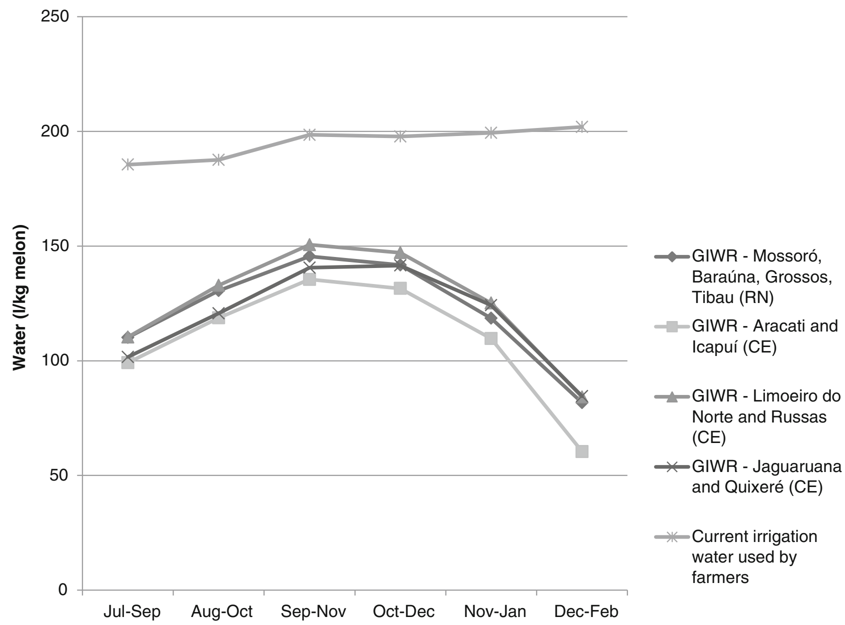

Fig. 2 Current and estimated irrigation water used by melon farmers in major subregions of the Low Jaguaribe and Açu region, Brazil, during different production periods of the growing season

size of fruits. Thus, excessive irrigation of melon fields in the LJA region may be reducing quality and the amount of exported fruits.

3.4 Sensitivity analysis

Major changes in yellow melon water consumption and IFA occur when the appropriate volume of water is applied, the efficiency of the irrigation system improves, and the production field location changes (Fig. 4). The error bar in Fig. 4 is due to variations in consumptive water, WSI, and IFA across the melon growing season in the various analyzed regions.

The scenario analysis shows that the IFA of melon production in open fields may decrease by 40 % in relation to the reference situation if the GIWR is used in melon fields and the yield is maintained at 23 t/ha (Scenario 1). If the irrigation system efficiency improves to 0.9 (scenario 2), IFA may be reduced by 52 %. Furthermore, a 73 % reduction in IFA may occur when the GIWR is applied and the irrigation efficiency of 0.9 and a yield of 40 t/ha is achieved (scenario 3). As shown in Section 3.3, yields correlate with melon irrigation and improve when the right amount of water is used.

Shifting production from Brazil to other world regions may also have a great effect on water consumption and IFA (Fig. 4). Melon production in Nicoya, Costa Rica (scenario 4), results in a decrease of 99 % in the impact. The main explanation for the low IFA of melons cultivated in Nicoya is the low monthly and annual WSI (0.015). The estimated GIWR for melons in this region is similar to that of melons produced in Brazil, Spain, and Italy.

On the other hand, melon production in Riverside Country, California, USA (scenario 5), requires higher water volumes for irrigation. The higher IFA for melons there is due to the long production period (135 days), the GWIR, and the WSI that cause an increase of 86 % in IFA compared to the Brazilian reference situation.

Melon production in Ciudad Real, Spain (scenario 6), and Lavello, Italy (scenario 7), has IFA values that are close to those of the reference situation. This is noted when comparing the minimum and maximum values of each scenario with the reference situation.

4 Discussion

Although this study evaluates the impact of melons in water availability, we have highlighted three main issues that may contribute to a broader discussion related to impacts of irrigated temporary crops on water availability. These issues are (1) use of range instead of average values for IFA, (2) dominance of water for irrigation in IFA, and (3) IFA as a way to improve the efficiency of water use in agriculture.

4.1 Use of range instead of average values for IFA

Many studies have presented the impact of food products on water availability. However, for all products, including melons and other temporary crops, results were presented as annual average values (Pfister et al. 2009, 2011; Ridoutt and Pfister 2010; Mekonnen and Hoekstra 2010).

The irrigation of temporary crops varies according to the climatic conditions of the production period in the

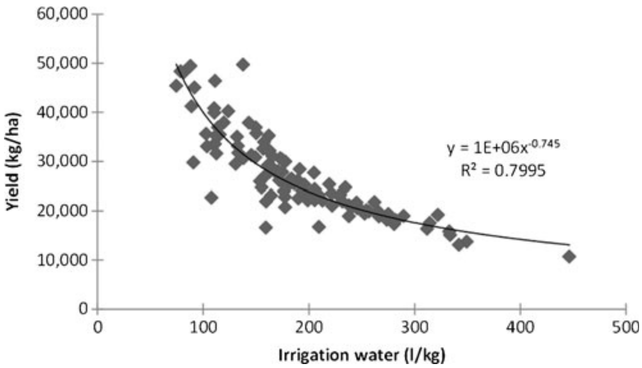

Fig. 3 Correlation between yield and irrigation water

growing season, as presented in this study of melons. Therefore, WC, WSI, and IFA values should be presented for each production period of the growing season. Average, minimum, and maximum WC, WSI, and IFA values should be presented when discussing the entire growing season.

4.2 Dominance of water for irrigation in IFA results

The IFA of melons is mainly due to the water used to irrigate melon plants in open fields. The contribution of other unit processes (such as production of fertilizers, pesticides, seeds, seedlings, transport) is minor and could be neglected. Ridoutt and Pfister (2010) made a similar observation for two processed food: pasta sauce and peanut. More than 90 % of the impact on water use of these products occurred at the agriculture stage. Considering these findings, in further impact studies of irrigated crops or of food products based on irrigated crops, the effort to collect water data and to identify water stress index may be directed to the agriculture stage.

4.3 IFA as a way to improve the efficiency of water use in agriculture

The comparison of IFA values based on current and estimated WC may lead to improvements in water efficiency in irrigated agriculture and reduction of a product impact on water availability. This is the case for melons in this study and may also be applicable to many irrigated crops cultivated all over the world.

Farmer's perceptions of excessive water use in irrigation are not always clear, especially in regions where water and energy costs are low and the irrigation systems are outdated. Water losses from irrigation systems are approximately 50 % in some developing countries (Kirda et al. 2009) and 35 % in the Low Jaguaribe and Açu region (Gondim et al. 2012).

Thus, the assumption that the current WC volume used in irrigation is equal to the estimated irrigation water requirement may underestimate the product's impact on freshwater availability in a region and reduce the possibility of improving water use in agriculture. Pfister et al. (2011) estimated water consumption for the production of melons and other crops at the country level and reached a figure of 89 l of on-farm expected water consumption to produce 1 kg of melon in Brazil. This estimated volume is lower than the one reported by farmers in the present study. This difference is mainly due to the excessive use of water to irrigate melons in the LJA region, as well as the fact that the average Brazilian climatic conditions differ from those in the LJA region.

Another issue relates to the consideration of the crop-growing season when estimating WC for irrigation. Many crops (e.g., melons, watermelons, tomatoes, grapes, and papayas) require controlled water supply through irrigation and are not cultivated during the rainy season. For those crops, little or no rain water is used, despite its availability during the rainy season. Therefore, the assumption that rain (green) water is used leads to mistakes in WC and IFA results.

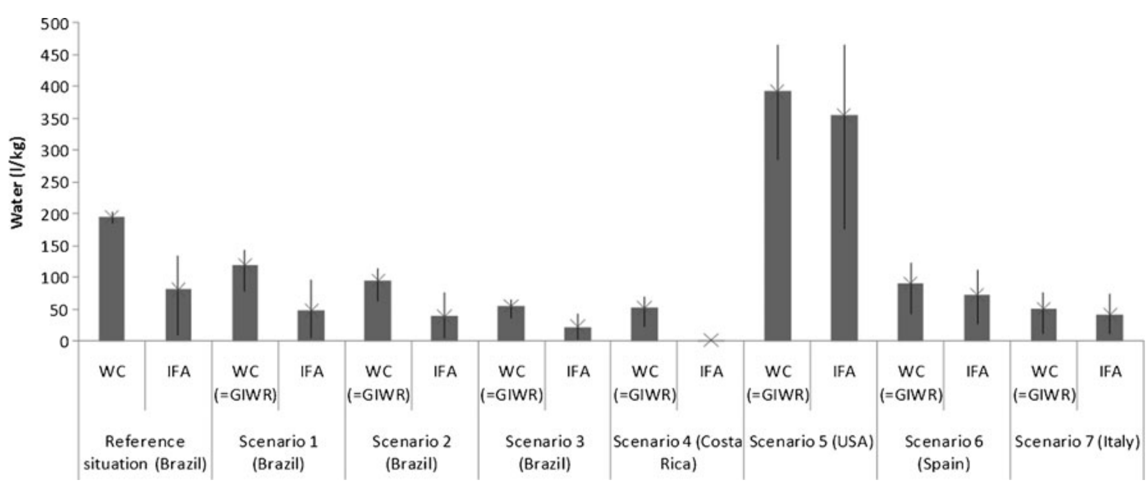

Fig. 4 Results of sensitivity analysis: water consumption (*WC*) and impact on water availability (*IFA*) of melon production for the reference situation and alternative scenario

Mekonnen and Hoekstra (2010) estimated water consumption of 212 l for 1 kg of melons produced in the States of Ceará and Rio Grande do Norte, where the regions in the present study are located. The values of Mekonnen and Hoekstra (2010) only relate to green water (that is, rain water). Using only green water in melon production would be possible if the growing season occurred during the rainy season (March to June). However, that is not the case in the Low Jaguaribe and Açu region as well as in other major world melon-producing regions (Aldaya and Llamas 2009; Cellura et al. 2012), because excessive soil moisture and high air humidity during the rainy season increase the occurrence of diseases in melon plants cultivated in open fields.

5 Conclusions

This study indicates that the impact of irrigated temporary crops on freshwater availability, such as melon, may be better presented as a range than as an average value. Presenting only average values may be misleading because of the large variation in water consumption and water stress among growing seasons.

The average water consumption throughout the life cycle of yellow melons in the LJA region is 198 l/kg of exported melons, and the IFA is 135 l H_2O-e/kg. The IFA ranges according to the production period in the melon growing season: 17 l H_2O-e/kg from October to December and 224 l H_2O-e/kg from July to September. Most of this impact (98 %) results from water consumption for open-field melon plant irrigation.

Furthermore, comparing current and estimated irrigation volumes may present an actual opportunity to optimize water consumption and reduce the impact of irrigated crops on freshwater availability. This comparison for melons shows that water consumption is at least 39 % higher than necessary when production occurs from September to November and varies among subregions and production periods in the LJA region. Efficient water use in irrigation would benefit farming economies by reducing impacts on water and costs.

A sensitivity analysis shows that the IFA of melon production in open fields may vary considerably with irrigation efficiency and farm location. Higher melon yield (40 t/ha) and a 73 % IFA reduction can be obtained when water is used more efficiently. Outside Brazil, the average impact can be as high as 466 l H_2O-e/kg for melons produced at Riverside County, California, and as low as 0.3 l H_2O-e/kg for melons produced in Nicoya, Costa Rica.

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