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Water footprint of Egyptian crops and its economics

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KEYWORDS

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Abstract Egypt lies in a dry region of the world. The management of water resources in dry areas is necessary to maintain the limited quantities of water available and to achieve an appropriate level of development, food security and stability. The current study aims to estimate the water footprint (WF) of Egyptian crops in the old and new lands inside and outside the Nile Valley and Delta. In addition, comparison of the WF of Egyptian crops with the global WF, and calculating the economics of the green and blue WF of Egyptian crops. Methodology of assessment was adopted from the water footprint assessment manual. Meteorological data during the study period were obtained from the weather station at Agricultural Research Center, and from Egyptian Meteorological Authority. Data of crop productivity were obtained from the Economic Affairs Sector-Ministry of Agriculture and Land Reclamation. The results showed that the contribution of green water to the total water footprint of Egyptian crops was small compared to blue water. Average total green plus blue water footprint ($WF_{green+blue}$) of Egyptian crops was about 680 m^3/ton. Egyptian crops recorded low WF values compared to the average global WF. In addition, average net return of the $WF_{green+blue}$ of Egyptian crops amounted to 10.25, 5.23 and 5.00 LE/m^3 for winter field crops and vegetables, summer field crops and vegetables, Nili and perennial crops, respectively.

1. Introduction and literature review

1.1. Introduction

Egypt lies in a dry region of the world. The management of water resources in dry areas is necessary to maintain the limited quantities of water available in these areas and to achieve an appropriate level of development, food security and stability.

In the coming view decades, global fresh water demand will be increased to meet the growing demand for various sectors. Improving crop water productivity comes as water scarcity

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increases so as to meet the growing demand for food under the limited fresh water resources. Therefore, the challenge is to produce more yields with less water and so reduce the water footprint of each unit of the crops produced (Mekonnon and Hoekstra) [1]. The water footprint of a product can be used to give policy makers on idea of how much water is being traded through imports and exports of the product (Kar et. al.) [2].

Water footprint is defined as the volume of fresh water used to produce the product, summed over the various steps of the production chain. The water footprint consists of three components of the green, blue and gray water footprint. The green water footprint defines as consumption of green water resources (rainwater insofar as it does not become run-off). The blue water footprint means consumption of blue water resources (surface and ground waters). Finally, the gray water footprint refers to pollution, and it is defined as the volume of fresh water that is required to assimilate to the load of pollutants given natural background concentration and existing ambient water quality standards (Hoekstra, Hoekstra et. al.) [3,4].

This study aims to assess the water footprint of Egyptian crops inside and outside the Nile Valley and Delta to identify the efficiency of water resources management for the Egyptian agriculture sector and compare the water footprint of Egyptian crops with the global water footprint. In addition, the study focuses on the economic assessment of the water footprint of Egyptian crops in order to help for deciding which crops can be exported or imported. In general, the most important objectives of the present study can be summarized in the following points:

1- Calculating the green and blue water footprints of Egyptian crops
2- Comparison of the water footprint of Egyptian crops with the global water footprint
3- Economics of the water footprint of Egyptian crops

1.2. Literature review

Muratoglu [5] explained that water scarcity is affecting many countries due to the unequal distribution of water resources, as well as increased demand. Therefore, improving the management and efficiency of water resources has become very important. In addition, Kim and Kim [6] added that, because food cannot be produced without water, demand-driven water management of agricultural and livestock products applying water footprints is needed for food security.

Regarding the results of Mekonnon and Hoekstra [7] on the green, blue and gray water footprint of global crop production, the global average water footprint per ton of crop increases from vegetables (~300 m^3/ ton), fruits (~1000 m^3/ ton), cereals (~1600 m^3/ ton) to pulses (~4000 m^3/ ton). Chu et al. [8] found that the largest water footprint intensity in the Hebei southern plain, North China recorded with the cotton crop while vegetables recorded the lowest values. In addition, Zhuo et al. [9] indicated that average WF per capita related to crop consumption reduced from 625 m^3/ cap in 1978 to 481 m^3/ cap in 2008, which may be due to improved crop productivity or increased crop imports from other countries with relatively small Marston et al. [10] indicated that as U.S. water resources become more stressed in the future, policy makers may require to consider tradeoffs between effective production and resilience to local and nonlocal supply chain shocks. Thaler et. al. [11] showed that sunflower, winter wheat and grain maize registered the highest WF in the semi arid regions. In addition, in more humid regions, which low temperatures were the main limiting factor on the crop yield potential and frequently led to higher WFs due to lower yields. Reis et al. [12] indicated that sugarcane is a predominant crop in São Paulo state, Brazil. This crop presented low water footprint (166.2 m^3/ ton) when compared to the literature, because of the high local yield. Also, tomato crop presented good results as compared with the global values. This indicates that sugarcane and tomatoes are favorable for cultivation in the São Carlos region. On the other hand, rice and groundnut crops demonstrate high water footprint compared to world averages. This may indicate the inadequacy of these crops in the region. Mekonnen and Leenes [13] showed that the water footprint is expected to increase by up to 22% as a result of climatic changes and change in land use by 2090. This requires action to improve water sustainability and protect the ecosystems on which it depends. Some measures include improve water productivity, setting standards, setting water footprint limits for each river basin, converting meals to low-water food stuff, and decreasing food waste. In the same way, Kahramanog et al. [14] added that sustainability in agricultural production has become a worldwide target. Success in such actions requires cross-cutting interactions. An incorporated, evidence-based approach is needed, coordinated by researchers, farmers, policy makers, civil society and private sector, in order to be successful. The integration of these sectors into the application could lead to increased water use efficiency and reduced food insecurity over the long period throughout the world.

2. Materials and methods

2.1. Study area

Study area is Egypt which located in Africa and Asia continents**.** A major portion of the country lies in the northeastern part of Africa, a small portion (Sinai Peninsula) located in the southwest corner of Asia. . Egypt has an area of 1,002,450 km^2.

According to the Sustainable Agricultural Development Strategy 2030 (SADS) [15] Egypt has been divided into five geographical regions, taking into account the characteristics structures of the agricultural regions.The five regions are Upper Egypt containing Asyut, Sohag, Qena, Aswan and the New Valley governorates; Middle Egypt including Giza, Bani-Sweif, Al-Fayoum, and Minya governorates; Middle Delta covering Al-Qaliobeya, Al-Menoufeya, Al-Gharbeya, Al-Dakahleya, Kafr El-Sheikh and Dumyat governorates; Eastern Delta including Al-Sharkeya, Port Said, Ismailia, Suez, Northern Sinai and Southern Sinai governorates; and Western Delta including Al-Beherah, Alexandria, Al-Nubareyah, and Matrouh governorates.

Due to the lack of climatic data, three stations within these regions were selected to calculate the water footprint in the old and newly reclaimed lands within the Nile Valley and Delta. These are, Kafr El-Sheikh, representing Middle Nile Delta (Lower Egypt); Giza and Asyut to represent Middle and Upper Egypt, respectively. Average climatic data of the three governorates were used to calculate the water footprint in the lands outside the Nile Valley and Delta

2.2. Meteorological data

Meteorological data were obtained from the weather station at Agricultural Research Center (ARC), Sakha station, Kafr El-Sheikh governorate, and from Egyptian Meteorological Authority (EMA). Average monthly maximum and minimum temperatures, relative humidity, wind speed and sunshine percent, in addition to total monthly rainfall through the study period (2017–2018) are presented in Table 1.

2.3. Crop productivity data

Data of crop productivity during the 2017/18 winter season and 2018 summer, Nili and perennials for the selected areas were obtained from the Economic Affairs Sector- Ministry of Agriculture and Land Reclamation (EAS-MALR, Volumes 2017–2018) [16].

2.4. Selected crops

In Egypt, there are two main seasons for the cultivation of field and vegetable crops, namely winter and summer seasons, and

Table 1 Average monthly weather data and total rainfall for Kafr El-Sheikh, Giza and Asyut in 2017and 2018.

Month	Tmax.	Tmin.	RH	WS	SS	RF	Tmax.	Tmin.	RH	WS	SS	RF
	Khafr El-Sheikh 2017						Khafr El-Sheikh 2018					
January	18.2	5.7	75	0.60	69	9.6	19.3	13.9	76	0.57	69	36.4
February	19.7	10.2	73	0.69	71	25.2	21.6	14.6	76	0.40	71	16.6
March	21.7	17.9	73	0.97	73	0.0	25.4	16.6	65	0.54	73	0.0
April	26.5	21.6	65	1.03	78	10.6	27.8	20.0	63	0.86	78	0.0
May	30.6	25.8	62	1.23	78	0.0	31.2	23.8	60	1.11	78	0.0
June	32.5	28.1	66	1.19	85	0.0	32.6	25.3	62	1.14	85	0.0
July	34.2	29.0	71	0.94	84	0.0	34.2	25.4	67	1.04	84	0.0
August	33.9	28.3	71	0.81	86	0.0	33.9	25.2	67	0.88	86	0.0
September	32.5	25.9	68	0.99	85	0.0	32.8	23.5	66	0.80	85	0.0
October	28.7	24.0	68	0.85	83	0.0	29.5	20.6	67	0.67	83	3.5
November	23.7	19.9	72	0.62	77	9.3	25.0	17.4	71	0.28	77	11.9
December	21.5	8.4	77	0.50	66	5.6	19.5	13.9	76	0.28	66	22.2
Average	**27.0**	**20.4**	**70**	**0.9**	**78**	**60.3**	**27.7**	**20.0**	**68**	**0.7**	**78**	**90.6**
	Giza 2017						**Giza 2018**					
January	19.4	6.9	60	1.7	68	0.0	20.4	9.0	58	1.8	68	0.0
February	21.5	8.0	60	1.7	72	0.8	24.7	12.5	53	1.4	72	3.0
March	25.4	12.0	48	1.7	73	0.0	28.8	14.4	44	1.5	73	0.0
April	29.2	15.0	41	2.0	75	1.6	29.9	15.9	43	1.6	75	0.0
May	34.6	19.4	35	2.0	80	0.0	35.1	21.1	42	1.9	80	0.0
June	36.7	22.3	36	2.1	86	0.0	36.5	23.1	42	2.1	86	0.0
July	38.2	24.5	42	2.0	85	0.0	37.9	24.4	46	1.9	85	0.0
August	37.1	24.6	46	2.0	85	0.0	37.1	25.1	47	2.0	85	0.0
September	34.9	22.2	46	1.9	85	0.0	35.6	24.1	48	1.9	85	0.0
October	31.0	18.5	47	1.9	82	0.0	31.1	20.2	49	1.8	82	0.0
November	25.5	13.7	54	1.7	78	0.0	26.9	15.5	58	1.8	78	0.0
December	23.9	12.4	64	1.5	70	0.0	22.0	11.2	61	1.5	70	2.0
Average	**29.8**	**16.6**	**48**	**1.8**	**78**	**2.4**	**30.5**	**18.0**	**49**	**1.8**	**78**	**5.0**
	Asyout 2017						**Asyout 2018**					
January	19.2	5.4	57	3.1	85	0.0	19.9	6.6	58	3.2	85	0.0
February	20.9	6.6	53	3.2	88	0.0	26.1	11.5	46	2.9	88	0.0
March	25.2	11.0	44	3.6	83	0.0	30.5	14.2	38	3.5	83	0.0
April	31.3	15.4	38	3.5	81	0.0	32.5	16.6	37	3.8	81	0.0
May	36.3	20.1	33	3.3	85	0.0	38.0	21.6	30	3.7	85	0.0
June	37.4	23.5	36	4.3	90	0.0	38.5	23.2	34	4.1	90	0.0
July	39.3	25.4	33	3.4	90	0.0	37.9	24.8	42	3.9	90	0.0
August	37.9	24.6	41	3.7	92	0.0	37.5	24.4	42	4.1	92	0.0
September	35.2	20.9	47	4.4	89	0.0	35.4	21.9	49	4.2	89	0.0
October	30.3	16.7	48	3.6	88	0.0	32.7	18.9	48	3.8	88	0.0
November	25.0	10.9	56	3.1	87	0.0	26.5	12.7	55	3.0	87	0.0
December	23.1	9.0	60	3.0	87	0.0	20.7	8.0	63	3.4	87	0.0
Average	**30.1**	**15.8**	**45**	**3.5**	**87**	**0.0**	**31.3**	**17.0**	**45**	**3.6**	**87**	**0.0**

where: Tmax. and Tmin. = maximum and minimum temperatures C°; RH = relative humidity (%); WS = wind speed (m/sec); SS = sunshine (%) and RF = total rainfall (mm).

sometimes there is a third season called the Nili season in addition to the perennial crops that remain in the land for a whole year. In the current study, 68 crops representing all seasons were selected for Egyptian agricultural crops. The chosen crops are shown in Table 2.

2.5. Methodology

Water footprint was studied using the methodology of water footprint assessment manual stated by Hoekstra et al. [4]. The total water footprint of the process of growing crops (WF_{proc}) is the sum of the green, blue and grey components:

$$\mathbf{WF_{proc}} = \mathbf{WF_{proc,green}} + \mathbf{WF_{proc,blue}} + \mathbf{WF_{proc,grey}}(\mathbf{volume/mass}) \quad (1)$$

The green component in the process water footprint of growing crop **(**$WF_{proc,green}$, m^3/ton) is calculated as the green component in crop water use (CWU_{green}, m^3/ha) divided by the crop yield (Y, ton/ha). The blue component ($WF_{proc,blue}$, m^3/ha) in a similar way:

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

Table 2 The Egyptian crops selected for the study.

Winter field crops	Summer field crops	Nili crops	Perennial crops
Barley	Cotton	***(field & vegetables)***	Apple
Chick peas	Ground nut	Beans (green)	Banana
Faba bean (green)	Maize	Beans (dry)	Date
Faba bean (dry)	Onion	Cabbage	Grapes
Fenugreek (dry)	Rice	Cucumber	Mango
Flax	Soybean	Egg plant	Olive
Garlic	Sunflower	Maize	Orange
Lentil	***Summer vegetables***	Pepper	Peach
Lupine	Beans (green)	Potato	Sugar cane
Onion	Beans (dry)	Squash	
Sugar beet	Cabbage	Sunflower	
Wheat	Cantaloupe	Tomato.	
Winter vegetables	Cucumber		
Beans (green)	Egg plant		
Beans (dry)	Jews mallow		
Cabbage	Okra		
Carrot	Pepper		
Cucumber	Potato		
Egg plant	Squash		
Lettuce	Sweet melon		
Peas (green)	Taro		
Peas (dry)	Tomato		
Pepper	Water melon		
Potato			
Squash			
Strawberry			
Tomato			

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

The green and blue components in crop water use (CWU, m^3/ha) are calculated by accumulation of daily evapotranspiration (ET, mm/day) over the complete growing period:

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

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

which ET_{green} represents green water evapotranspiration and ET_{blue} blue water evapotranspiration. The factor 10 is meant to convert water depth in millimeters into water volumes per land surface in m^3/ha. The summation is done over the period from the first day of planting till the day of harvest "lgp" (length of growing period).

CROPWAT8.0 model developed by the Food and Agriculture Organization and the United Nations was used to estimate crop evapotranspiration, which is based on the method described in FAO No. 56 by Allen et al. [17]. The estimation was done under optimal conditions. The model calculates crop water requirements (CWR), effective precipitation ($P_{eff.}$) and irrigation requirements (IR). The CWR is calculated by multiplying the reference evapotranspiration (ETo) by the crop coefficient (Kc):

$$\mathbf{CWR} = \mathbf{ETo x Kc} \quad (6)$$

The Kc values of the crops used in this study were obtained from FAO No. 56 and some values were adjusted according to the results of actual field trials in Egypt.

When the CWR are fully (optimal conditions or no water limitations to crop growth), the ETc will be equal to CWR:

$$\mathbf{ETc} = \mathbf{CWR} \quad (7)$$

Green and blue water evapotranspiration (ET_{green} & ET_{blue}) can be estimated as follows:

$$\mathbf{ET_{green}} = \mathbf{min}(\mathbf{ETc}, \mathbf{P_{eff}}) \quad (8)$$

$$\mathbf{ET_{blue}} = \mathbf{max}(0, \mathbf{ETc} - \mathbf{P_{eff}}) \quad (9)$$

Green water consumption (ET_{green}) is calculated by the amount of effective rainfall that contributes to the crop water use (so that it reaches the roots of the plant and the plant can benefit from it). Blue water consumption (ET_{blue}) includes the total crop water use (ETc) minus the amount of effective rain (if any) .

The CropWat model calculates effective rain as well as total ETc and through the results of the model the contribution of green and blue waters can be concluded, each of them separately.

With regard to the calculation of the gray water footprint, since there is no appropriate data, the natural concentration in the receiving water body is assumed to be zero.

2.5.1. Economics of green and blue water footprint of Egyptian crops

Economics of the water footprint of agricultural crops in Egypt were made through net return per hectare per crop (data were obtained from EAS-MALR, Volumes 2017–2018) [16]. Net return per ton was calculated and then calculated the economics of the green and blue water footprint and finally col-

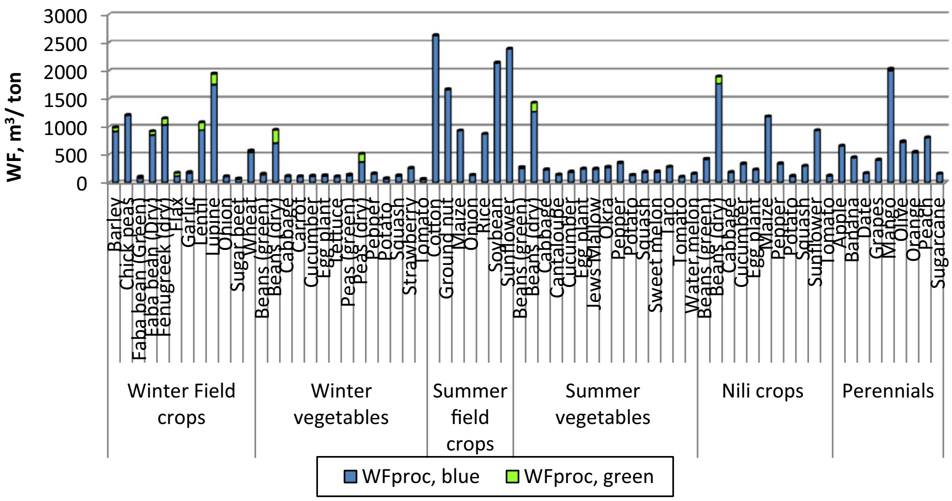

Fig. 1 Green - blue water footprint (WF) of winter, summer, Nili and perennial crops in the old lands inside the Nile Valley and Delta. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

lected to obtain the net return of the water footprint (LE) per unit of water used (m^3).

3. Results

Green and blue water footprint has been calculated for 68 Egyptian crops in the old and new lands inside and outside the Nile Valley and Delta. Calculations were made for 2017/18 for winter crops, 2018 for summer, Nili and perennial crops.

3.1. Water footprint (WF) of crops in the old and new lands inside the Nile Valley and Delta

Results as presented in Fig. 1 illustrate the WF of crops in the old lands. It is clear that the highest values of green water footprint (WF_{green}) found for winter dry beans, lupine, summer dry beans, dry peas, lentil, Nili dry beans and dry fenugreek. The respective values were 238, 195, 157, 145, 138, 126 and 115 m^3/ton. Average values of WF_{green} were 61 m^3/ton for winter field crops, 34 m^3/ton for winter vegetables, 1 m^3/ton for summer field crops, 17 m^3/ton for summer vegetables, 14 m^3/ton for Nili crops and 9 m^3/ton for perennial crops. Regarding the blue water footprint (WF_{blue}), the highest ones registered for cotton (2626 m^3/ton), summer sunflower (2389 m^3/ton), soybean (2141 m^3/ton) and mango (2002 m^3/ton). Average values of WF_{blue} ranged from 182 m^3/ton for winter vegetables up to 1537 m^3/ton with summer field crops.

With respect to the WF of crops in the new lands inside the Nile Valley and Delta, results as recorded in Fig. 2 indicate that the highest WF_{green} of crops found for lupine, winter dry beans and dry fenugreek. The respective values were 347, 174 and 116 m^3/ton. Average values of WF_{green} for winter field

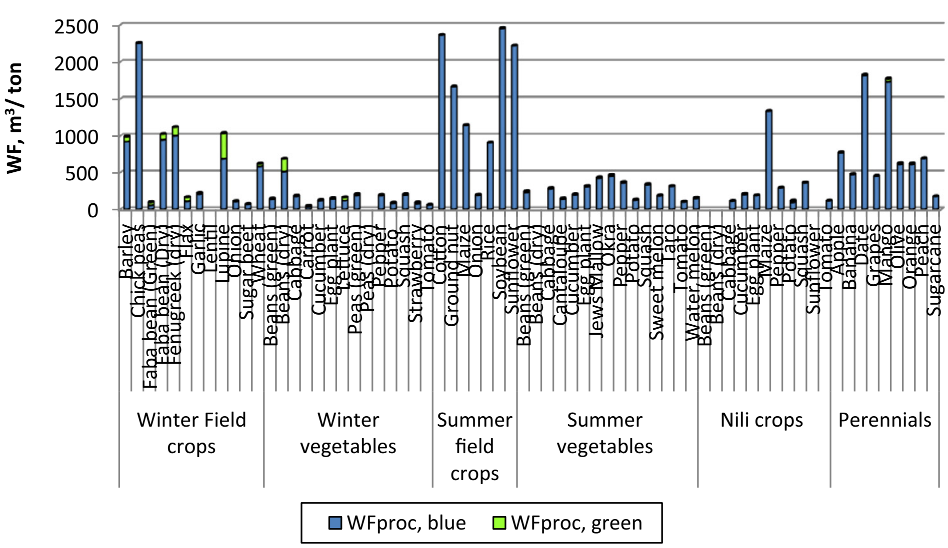

Fig. 2 **Green-blue water footprint (WF) of winter, summer, Nili and perennial crops in the new lands inside the Nile Valley and Delta.** Note: In this figure and other figures and tables, the absence of some values reflects the absence of crop cultivation under the conditions of this type of land. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

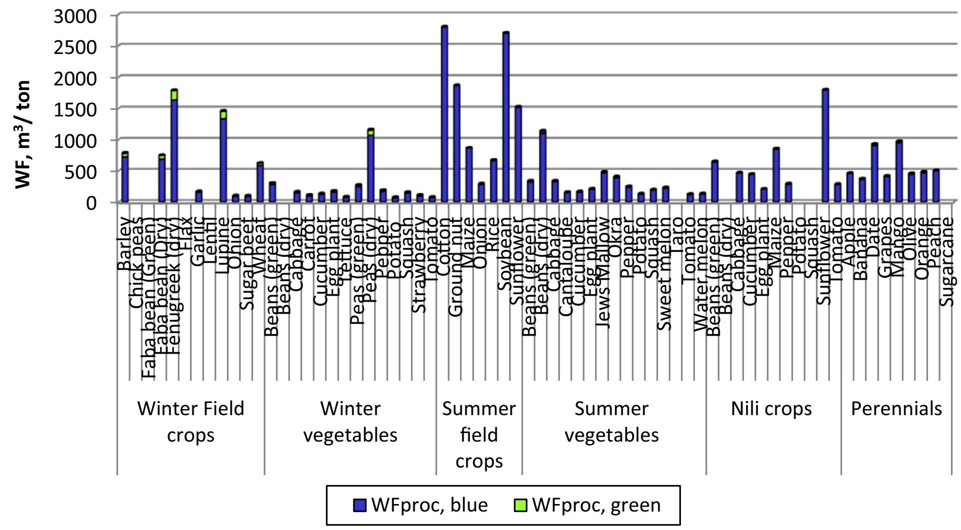

Fig. 3 Green - blue water footprint (WF) of winter, summer, Nili and perennial crops in the new lands outside the Nile Valley and Delta. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

crops, winter vegetables, summer field crops, summer vegetables, Nili crops and perennials amounted to 70, 25, 1, 8, 5 and 11 m^3/ton, respectively. As for WF_{blue} , the crops with the highest values of the WF_{blue} were soybean (2455 m^3/ton), cotton (2366 m^3/ton), chickpeas (2256 m^3/ton) and summer sunflower (2220 m^3/ton). Average values of WF_{blue} varied between 156 m^3/ton for winter vegetables and 1564 m^3/ton for summer field crops.

3.2. Water footprint of crops in the new lands outside the Nile Valley and Delta

Agricultural areas outside the Nile Valley and Delta are all new lands, so the WF calculations were made only on the new lands.

The results in Fig. 3 present that the highest values of WF_{green} recorded with the following crops: fenugreek (154 m^3/ton), lupine (120 m^3/ton), dry peas (84 m^3/ton), dry faba bean (62 m^3/ton) and barley (60 m^3/ton). Average values of WF_{green} ranged from 0.4 m^3/ton for summer field crops up to 57 m^3/ton for winter field crops.

As for WF_{blue}, the values ranged between 93 and 1639 m^3/ton for winter field crops, 72 and 1076 m^3/ton for winter vegetables, 288 and 2802 m^3/ton for summer field crops, 126 and 1108 m^3/ton for summer vegetables, 209 and 1801 m^3/ton for Nili crops, 370 and 953 m^3/ton for perennials. Average values of WF_{blue} in the new lands outside the Nile valley and Delta were 666, 217, 1534, 300, 624 and 567 m^3/ton for the respective of winter field crops, winter vegetables, summer field crops, summer vegetables, Nili crops and perennials.

3.3. Comparison of the WF of Egyptian crops inside and outside the Nile Valley and Delta

Results as recorded in Fig. 4 showed different WF values of crops grown inside and outside the Nile Valley and Delta.

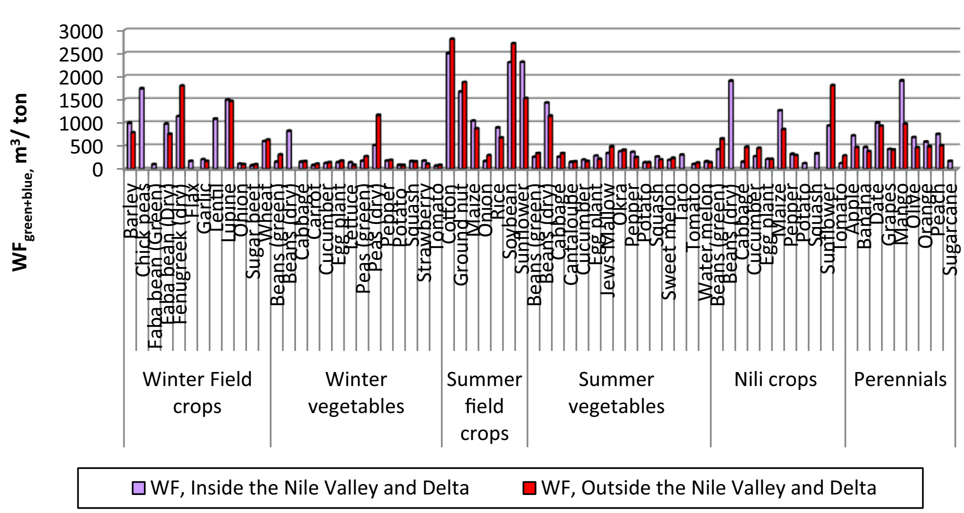

Fig. 4 Comparison of the water footprint ($WF_{green+blue}$) of Egyptian crops inside and outside the Nile Valley and Delta. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

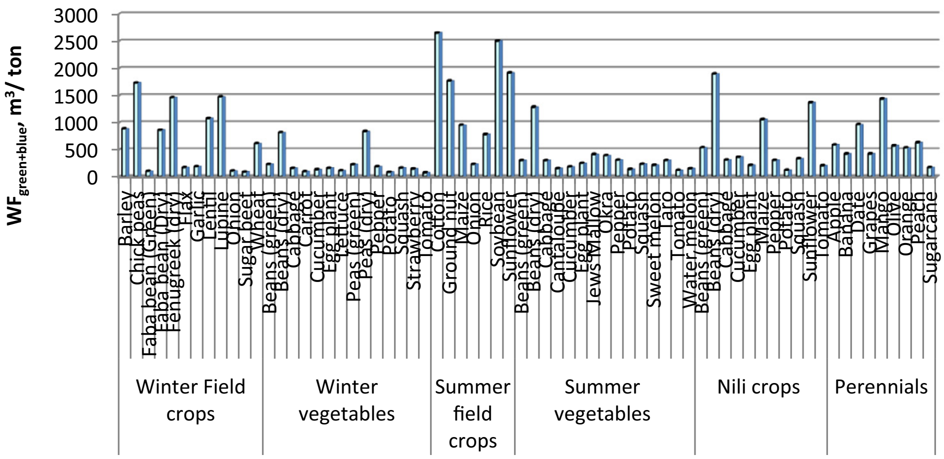

Fig. 5 Average total green plus blue water footprint ($WF_{green+blue}$) of Egyptian winter, summer, Nili and perennial crops. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The low values of the WF of crops within the Nile Valley and Delta compared to those outside the Nile Valley and Delta recorded with dry fenugreek, sugar beet, wheat, green beans, cabbage, green and dry peas, cotton, ground nut, soybean and tomato. The decrease in WF values for these crops is due to increase productivity compared to productivity outside the Nile Valley and Delta. Therefore, this study proposes to increase the area planted from these crops inside the Nile Valley and Delta.

On the other hand, other crops have given low WF values outside the Nile Valley and Delta, these are barley, dry faba bean and all perennial crops (except sugarcane, because it's not grown outside the Nile Valley and Delta).

3.4. Average total WF of Egyptian crops

Average total WF of Egyptian crops (Fig. 5) was calculated through the process of collecting the green and blue WF of each crop within the Nile Valley and Delta, as well as, in the same way, the calculation was done outside the Nile Valley and Delta. After that, an average values were taken inside and outside the Nile Valley and Delta to produce the average total green plus blue WF ($WF_{green+blue}$) of Egyptian crops.

Values of $WF_{green+blue}$ of winter crops varied from 86 to 1733 m^3/ton for winter field crops and 72 to 836 m^3/ton for winter vegetables. The average total $WF_{green+blue}$ of winter field crops and vegetables amounted to 730 and 243 m^3/ton, respectively.

Concerning the values of summer crops, the highest and lowest ones registered with cotton (2649 m^3/ton) and onion (230 m^3/ton) for summer field crops; dry beans (1285 m^3/ton) and tomato (117 m^3/ton) for summer vegetables. Average total $WF_{green+blue}$ of summer field crops and vegetables were 1543 and 315 m^3/ton, respectively.

In addition, the results of Nili and perennial crops illustrate that the values ranged from 119 to 1898 m^3/ton for Nili crops, and 169 to 1438 m^3/ton for perennials. The average total $WF_{green+blue}$ amounted to 609 and 638 m^3/ton for Nili and perennial crops, respectively.

3.5. Comparison of the $WF_{green+blue}$ of Egyptian crops with the global $WF_{green+blue}$

Results of the global water footprint of agricultural crops used in this study were obtained from the study of Mekonnon and Hoekstra [18]. The comparison was based on the average total $\mathbf{WF_{green+blue}}$ of the crops under study.

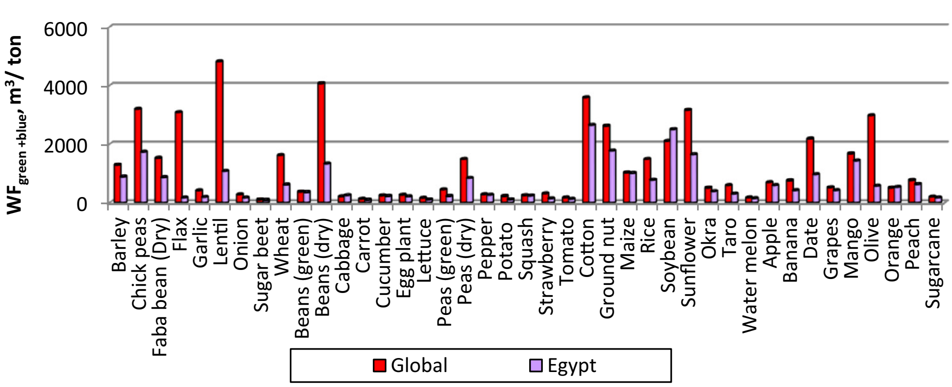

Fig. 6 Comparison of the $WF_{green+blue}$ of Egyptian agricultural crops with the global $WF_{green+blue}$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

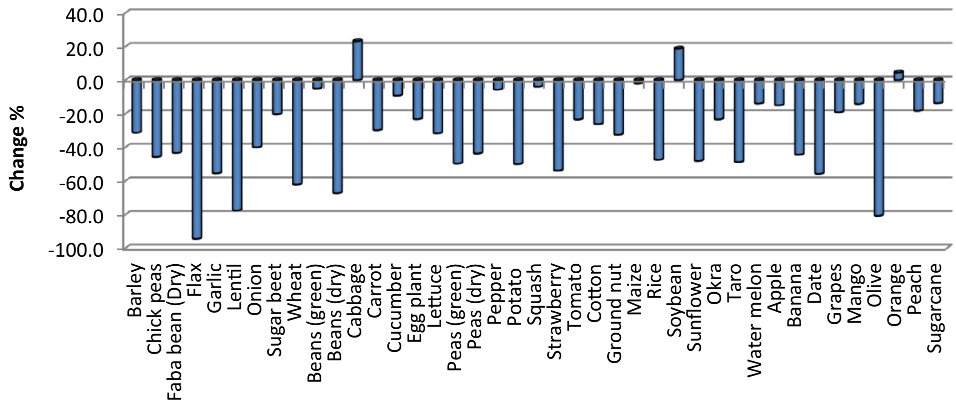

Fig. 7 Percentage change between $WF_{green+blue}$ of Egyptian crops and global $WF_{green+blue}$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The results in Fig. 6 show that most Egyptian crops have recorded low WF values compared to those at the global level. On the other hand, there are some Egyptian crops registered higher values than the global values, such as cabbage, soybean and orange. In general, the average total $WF_{green+blue}$ of Egyptian crops is 664 m^3/ton, while the global average for the same crops is 1232 m^3/ton.

Percentage change between Egyptian WF and global WF are presented in Fig. 7. The results reveal that flax, garlic, lentil, wheat, dry beans, potato, strawberry, dates and olives recorded low values for the Egyptian WF. The percentage change has decreased by about 50% or more for Egyptian crops compared to the global average. While, Egyptian crops of cabbage, okra, and orange have recorded high values compared to their global counterparts, the increase has ranged from 5 to 23%.

The obvious differences in Fig. 6 of the water footprint values of Egyptian crops and the global average may be due to

Table 3 Economics of green and blue water footprint (LE/ m^3) of winter field and vegetable crops.

Crop		Net return of the water footprint (WF) of Egyptian crops (LE/ m^3)		
		WF_{blue}	WF_{green}	WF_{total}
Winter Field crops	Barley	1.72	0.14	1.86
	Chick peas	9.31	0.01	9.32
	Faba bean (Green)	23.78	10.92	34.70
	Faba bean (Dry)	5.29	0.45	5.74
	Fenugreek (dry)	4.13	0.42	4.55
	Flax	1.57	0.80	2.37
	Garlic	8.29	0.64	8.93
	Lentil	6.41	0.94	7.35
	Lupine	4.26	0.65	4.91
	Onion	11.14	0.63	11.77
	Sugar beet	2.83	0.17	3.00
	Wheat	1.24	0.08	1.32
Winter vegetables	Beans (green)	12.20	0.93	13.13
	Beans (dry)	15.12	5.10	20.22
	Cabbage	2.61	0.16	2.78
	Carrot	9.73	0.87	10.60
	Cucumber	5.91	0.40	6.31
	Egg plant	7.89	0.49	8.38
	Lettuce	15.62	2.50	18.12
	Peas (green)	8.97	0.79	9.76
	Peas (dry)	17.03	2.70	19.73
	Pepper	7.06	0.44	7.49
	Potato	9.05	0.91	9.96
	Squash	5.86	0.36	6.22
	Strawberry	19.79	1.23	21.03
	Tomato	15.90	1.09	16.99
Average		8.95	1.30	10.25

Currency equivalents (as of October 2020): US $1.00 = 15.6 LE different weather conditions, the length of the growing season, cultivated varieties, fertilization rates, etc.

3.6. Economics of the water footprint ($WF_{green+blue}$) of Egyptian crops

In order to complete the picture in giving a recommendation regarding crops that can be exported or imported or increased in the area planted in the appropriate region, an economic assessment of the WF of Egyptian crops was carried out.

Results as tabulated in Tables 3-5 indicate the economics of the WF_{green}, WF_{blue} and $WF_{total\ (green+blue)}$ of Egyptian crops. The results of winter crops (Table 3) clearly show that the net return of the WF_{total} unit was higher with some crops compared to other. Superior crops can be arranged in descending order as follows: green faba bean > strawberry > dry beans > dry peas > lettuce > tomato > green beans > onion > carrot. The respective values are 34.70, 21.03, 20.22, 19.73, 18.12, 16.99, 13.13, 11.77 and 10.60 LE/m^3. While the lowest values found for wheat (1.32 LE/m^3), barley (1.86 LE/m^3) and flax (2.37 LE/m^3). Average net return from WF unit for winter crops is 10.25 LE/m^3.

Concerning the economic assessment of summer crops, the results in Table 4 showed that the superior crops in the net return are dry beans (12.84 LE/m^3), sweet melon (11.88 LE/m^3), tomato (10.62 LE/m^3), green beans (10.00 LE/m^3) and water melon (8.63 LE/m^3). However, the lowest ones found for soybean (0.23 LE/m^3) and sunflower (0.45 LE/m^3). Average net return of the WF for summer crops is 5.23 LE/m^3.

Regarding the net return of the WF unit for Nili and perennial crops, results in Table 5 indicatethat the lowest net return found for sunflower (0.63 LE/m^3) and maize (0.86 LE/m^3). While, pepper followed by eggplant, dry beans and apple are the highest ones. Values of net return of the WF for the previous crops respectively are 9.86, 9.51, 8.69 and 8.48 LE/m^3. The overall average of net return for Nili and perennial crops is 5.00 LE/m^3.

4. Discussion

Agricultural land in Egypt is cultivated in two main seasons of winter and summer, and sometimes a third season of Nili, in addition to the perennial crops that remain in the land for a whole year. As a result of the cultivation of land in Egypt more than once a year, the cropping intensity in Egypt in recent years has reached more than 170%.

This study focuses on calculating the WF of the different seasons applied in Egyptian agriculture. Tables 6 and 7 summarize the results of the green and blue water footprints of these agricultural seasons as well as the values of the water footprint inside and outside the Nile Valley and Delta.

From the results of Table 6, it is clear that values of WF ranged between 1 and 63 m^3/ton for WF_{green}, 211 and 1542 m^3/ton for WF_{blue}. The overall average is 22 m^3/ton for WF_{green} and 658 m^3/ton for WF_{blue}. The results added that WF_{blue} recorded high values compared to WF_{green} for all Egyptian crops under study since the annual rainfall is low and the agriculture in Egypt is essentially fully irrigated. So, the WF_{blue} contributes a large percentage to the total water footprint of Egyptian crops. Meanwhile, the results recorded noticeable values for the WF_{green} of winter crops compared to other crops.

Regarding the results in Table 7, values of WF range from 211 to 1551 m^3/ton for crops inside the Nile Valley and Delta,

Table 4 Economics of green and blue water footprint (LE/ m^3) of summer field and vegetable crops.

Crop		Net return of the water footprint (WF) of Egyptian crops (LE/ m^3)		
		WF_{blue}	WF_{green}	WF_{total}
Summer field crops	Cotton	2.84	0.00	2.84
	Ground nut	2.98	0.00	2.98
	Maize	0.72	0.00	0.72
	Onion	5.33	0.10	5.43
	Rice	0.97	0.00	0.97
	Soybean	0.23	0.00	0.23
	Sunflower	0.45	0.00	0.45
Summer vegetables	Beans (green)	9.45	0.55	10.00
	Beans (dry)	11.89	0.95	12.84
	Cabbage	4.28	0.12	4.40
	Cantaloupe	2.08	0.08	2.16
	Cucumber	4.40	0.13	4.53
	Egg plant	3.79	0.08	3.87
	Jews Mallow	2.39	0.07	2.47
	Okra	10.69	0.37	11.06
	Pepper	2.26	0.05	2.31
	Potato	5.71	0.22	5.94
	Squash	5.50	0.17	5.67
	Sweet melon	11.49	0.39	11.88
	Taro	4.93	0.04	4.97
	Tomato	10.28	0.34	10.62
	Water melon	8.38	0.25	8.63
Average		5.05	0.18	5.23

Table 5 Economics of green and blue water footprint (LE/ m^3) of Nili and perennial crops.

Crop		Net return of the water footprint (WF) of Egyptian crops (LE/ m^3)		
		WF_{blue}	WF_{green}	WF_{total}
Nili crops	Beans (green)	5.52	0.07	5.59
	Beans (dry)	8.12	0.58	8.69
	Cabbage	2.17	0.02	2.19
	Cucumber	4.12	0.04	4.15
	Egg plant	9.46	0.05	9.51
	Maize	0.86	0.00	0.86
	Pepper	9.80	0.06	9.86
	Potato	2.36	0.37	2.73
	Squash	5.98	0.03	6.01
	Sunflower	0.63	0.00	0.63
	Tomato	5.65	0.04	5.68
Perennials	Apple	8.44	0.04	8.48
	Banana	7.01	0.11	7.12
	Date	2.05	0.03	2.07
	Grapes	7.07	0.04	7.11
	Mango	3.41	0.06	3.48
	Olive	5.13	0.12	5.25
	Orange	3.67	0.07	3.75
	Peach	4.74	0.02	4.76
	Sugarcane	2.00	0.02	2.02
Average		4.91	0.09	5.00

Table 6 Green - blue water footprint (m^3/ ton) of Egyptian crops.

Crop	WF_{green}	WF_{blue}	WF_{total}
Winter Field crops	63	667	730
Winter vegetable crops	32	211	243
Summer field crops	1	1542	1543
Summer vegetable crops	13	302	315
Nili crops (field and vegetable)	15	595	609
Perennials	9	629	638
Average	22	658	680

and from 274 to1534 m^3/ton outside the Nile Valley and Delta. The overall averages of WF inside and outside the Nile Valley and Delta, respectively, are 683 and 676 m^3/ton. Finally, the overall average of the WF of Egyptian crops as described in Tables 6 and 7 is 680 m^3/ton.

5. Conclusion

Improving crop water productivity in order to meet the growing demand for food is very important, especially in arid and semi-arid areas, which are suffering from limited water resources. The aim of the present investigation is to assess green and blue water footprints of Egyptian crops inside and outside the Nile Valley and Delta. In addition, comparing the Egyptian water footprint with the global water footprint. Finally, the economics of the green and blue water footprint of Egyptian crops were included in this study.

Methodology of assessment was adopted from Hoekstra et al., 2011. Meteorological data during 2017–2018 were obtained from the weather stations at ARC and EMA. In addition, data of crop productivity were obtained from EAS-MALR.

The results indicated that average values of WF_{green} and WF_{blue} in the old lands inside the Nile Valley and Delta are 25 and 546 m^3/ton, respectively. The respective averages in

Table 7 Average total water footprint (m^3/ ton) of Egyptian crops inside and outside the Nile Valley and Delta.

Crop	$WF_{Inside\ the\ Nile\ Valley\ and\ Delta}$	$WF_{Outside\ the\ Nile\ Valley\ and\ Delta}$	$WF_{average}$
Winter Field crops	721	739	730
Winter vegetable crops	211	274	243
Summer field crops	1551	1534	1543
Summer vegetable crops	321	309	315
Nili crops (field and vegetable)	549	669	609
Perennials	744	531	638
Average	683	676	680

the new lands inside the Nile Valley and Delta are 22 and 541 m^3/ton.

As for the averages outside the Nile Valley and Delta (new lands only), the values of 15 and 562 m^3/ton of the WF_{green} and WF_{blue} scoring respectively.

With regard to comparing the WF of Egyptian crops with the global average, the results indicated that most Egyptian crops recorded low values compared to the global average.

Concerning the results of the economic assessment of the WF unit of Egyptian crops, the important results can be summarized in the following points:

- Average net return from the green plus blue WF unit (WF_{total}) of the winter crops is 10.25 LE/ m^3. The crops of green faba bean, dry beans, lettuce, dry peas, strawberry and tomato have recorded the highest ones. The values ranged from about 17 up to 34 LE/m^3.
- Average net return from WF_{total} of summer crops is 5.23 LE/m^3. The crops of green and dry beans, okra, sweet melon, tomato and water melon recorded the highest values, which ranged from about 9 to 13 LE/m^3.
- Average net return from WF_{total} of the Nili and perennial crops is 5.00 LE/m^3. The crops of dry beans, eggplant, pepper and apple obtained the highest ones. They ranged from about 9 to 10 LE/m^3.
- Finally, the overall average net return of the WF unit for Egyptian crops is 7.08 LE/m^3.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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