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Water footprint for citrus production in Egypt: a case study of Navel orange

Waleed Fouad Abobatta[1,*] and Ahmed A. Farag[2]

1, Horticulture Research Institute, Agricultural Research Center, Giza, Egypt
2, Central Laboratory for Agricultural Climate, Agricultural Research Center, Giza, Egypt

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***Corresponding author:**
Horticulture Research Institute, Agricultural Research Center, Giza, Egypt.

Email: wabobatta@arc.sci.eg

ABSTRACT

Purpose: Citrus is one of the most significant fruit crops in the world, and there are huge amounts of citrus in Egypt, especially orange. Shortage of water resources is the main challenge for citrus production, therefore, proper management of water resources for orange orchards is essential in Egypt. **Research Method:** The current study's objective was to calculate the water footprint components of orange production in four governorates (Beheira, Gharbia, Menoufia, and Sharqiya) during 2020-2023. **Findings:** Data indicated that different irrigation rates affected tree growth, tree yield, total yield, yield efficiency, and fruit quality. Results showed that trees grown in the Salhyia area recorded the highest values of canopy ratio increment (42.21%), N leaf content (2.46%), yield efficiency (5.92 kg/m3), tree yield (132.00 kg/tree), total yield (52.80 tons/ha), TSS/TA ratio value (11.75), and the lowest acidity value (0.99 %). The highest values of leaf K content (1.76%), and vitamin C (42.83) were recorded in Al Mahalla El Kubra region, while the highest P leaf content (0.314%) was observed in Ashmoun district. Data showed that water use efficiency was lower in surface irrigation with a value of 3.71 kg orange/m^3 water and higher in drip irrigation with a value of 3.81 kg orange/m^3 water. **Research limitations:** There was no limitation. **Originality/Value:** Regarding water footprint components, data revealed that the drip irrigation system had lower green, grey and total water footprint values than surface irrigation. In contrast, the blue water footprint was the height under the drip irrigation system rather than the surface irrigation system.

INTRODUCTION

In Egypt, the Nile Delta, Nubaria region in Beheira Governorate, and Salhyia region in Sharqiya Governorate are among the most important citrus-growing areas. Egypt produces a wide variety of citrus fruits, Oranges, Mandarins, lemons, and grapefruits are among the most popular and mainly consumed as fresh fruit, juice, or exporting (Abobatta, 2019). Oranges have a significant position in Egyptian citrus production and represent the major citrus crop in Egypt. Navel orange (*Citrus sinensis* (L.) Osbeck), is one of the significant varieties and occupies the first place in citrus production in Egypt, known for its unique characteristics and exceptional taste, so, it has become a favorite among local and international consumers. The cultivated areas of Navel oranges have steadily increased to reach 67850 ha, representing 31% of the total citrus cultivated (Annual Report, 2023). Under irrigated cultivation systems, enhancing plant growth is greatly depending mineral fertilizing. Citrus orchards require reasonable amounts of irrigation water about 10,000 m^3 /ha/ yearly and 300 nitrogen units/ha / yearly for growth and fruiting in Egypt (Arafat & Helal, 2021).

The water footprint (WF) concept has emerged as a new attitude for assessing the sustainability of water use, particularly in the agricultural sector. The water footprint provides a comprehensive measure of water use by considering not only direct water consumption (irrigation water) but also the indirect water use embedded in the production of agricultural products (Lovarelli et al., 2016). Water footprint is a great indicator of the efficiency of water used in different processes, and it includes direct and indirect use of water to produce goods or services during a certain period measured in liters used per unit produced of product or service (Hoekstra et al., 2009). Analyzing WF helps researchers to define the water use situation, and then estimate the imported/exported amounts of water (Tuninetti et al., 2015). The water footprint assessment provides a quantitative framework to analyze the amount of water set in agricultural goods and the efficiency of water use when the metric is computed per unit weight of the products (hereafter referred to as the unit water footprint (Galán-Martín et al., 2017). The water footprint has three components, including green, blue and grey. The footprint of green water mentions to the consumption of rainwater stored in the soil as the soil moisture (Yi et al., 2024). Bluewater is defined as the surface water and groundwater consumed in the chain of production (Galán-Martín et al., 2017). Grey water refers to the volume of freshwater required to dilute the chemical fertilizers and pesticides (Hoekstra et al., 2011). Due to population increases, food security and sustainable management of water resources are essential; hence, WF is a dynamic concept for management of water resources in any sector, especially in agriculture. These concepts are considered by many researchers in various fields; for instance, the study of water footprints on citrus fruits in South Africa (Munro et al., 2016). The water footprint is affected by agricultural management more willingly than the regional climate and could be controlled by better management of all agricultural inputs and improving water use efficiency in agriculture (Lu et al., 2016).

The WF takes into account the impacts that arise from the cumulative effect of all activities, with the understanding that the agricultural water footprint (WF) is the sum of the WF of each crop grown in an area to identify the periods in which extractions are unsustainable (Lovarelli et al., 2016).

This study evaluates the water footprint of navel oranges under flood and drip irrigation systems in citrus orchards by studying five main regions of citrus production in Egypt and estimating the green, blue, and grey water footprint to improve water management in Egypt. Knowledge of water footprint in citriculture is an important issue in planning efficient water use and improving productivity, sustainability and competitiveness of irrigated crops (Imbernón-Mulero et al., 2024).

The main goals of this work are the estimated water footprint of navel oranges, increasing water use efficiency, improving tree growth, and sustaining citrus crop production at different locations in Egypt.

MATERIALS AND METHODS

Study areas

In Egypt, Navel orange is mainly grown in Delta, Nubaria and Salhyia regions. The study and water management measurements were conducted on mature orange (*Citrus sinensis* L.) trees (15 years old) in commercial orchards in four governorates (Beheira, Gharbia, Menoufia, and Sharqiya) as shown in (Table 1).

Data collection

Certain criteria were used to determine the WFP of Orange trees in response to various irrigation water quantities and N fertilization rates. Data obtained were vegetative growth, leaf mineral contents, yield (ton.ha^{-1}), fruit quality, and water use efficiency during the study period from 2020 to 2023.

The vegetative growth of the tree is expressed as the canopy volume increment percentage as follows (1):

$$\text{The yearly increment percentage} = [(TCV2 - TCV1)/TCV1] \times 100 \qquad (1)$$

Where TCV1: is the tree canopy volume at the beginning of the growth season and TCV2 is the tree canopy volume at the end (m^3) according to equation (2) of Zekri (2000).

$$\text{Canopy volume} = 0.52 \times \text{tree height} \times (\text{diameter}^2) \qquad (2)$$

Various agricultural practices were conducted, including pruning, organic fertilization, pest control, etc., according to the Egyptian Ministry of Agriculture and Land Reclamation recommendations.

Table 1. Four years (2020–2023) of water supply (m^3/ha), Rainfall (mm), and nitrogen fertilizer (kg/ ha) applications for Navel Orange orchards in the four governorates.

Site	Al-Shorouk	Nubaria	El- Mahalla El-Kubra	Ashmoun	Salhyia
	Irrigation water supply (m^3/ha)				
First season	10560	9600	9423	9120	10800
Second season	10800	10320	8880	9360	10560
Third Season	11400	10800	9360	9840	11100
Fourth Season	12720	12000	10320	10320	11880
Average	11370	10680	9496	9660	11085
	Rainfall (mm)				
First season	90.8	90.8	72.9	68.6	15.3
Second season	20.8	20.8	44.9	33.1	12.2
Third Season	33.4	33.4	27.6	25.2	15.0
Fourth Season	19.9	19.9	21.4	17.9	15.2
	N supply (kg/ ha)				
First season	432	350	550	389	411
Second season	428	353	414	375	425
Third Season	400	386	361	428	439
Fourth Season	452	400	425	400	425
Average	428.00	372.25	437.50	398.00	425.00

Determination of leaf mineral contents

Every season and from each site, 20 mature leaves were washed with distilled water and dried at 70°C, and plant samples were wet digested using H_2O_2 and H_2SO_4 according to the procedure described by Bankaji et al. (2023) to determine the macro elements.

Yield and its components

Twenty fruits were picked up at harvesting time in the second half of December each season (2020, 2021, 2022, and 2023) from each experimental site to determine fruit quality parameters. The number and weight of fruit per tree were counted in the orchards to get the tree yield (kg), yield (ton) /ha, and yield efficiency (kg/m^3), according (Biratu et al., 2023). TSS % was determined using hand refractometer. Total titratable acidity percentage in fruit juice was estimated as anhydrous citric acid and Vitamin C (as mg/ 100 g pulp) was determined according (A.O.A.C., 2000), then T.S.S/acid ratio was calculated.

Effective Rainfall

An empirical formula developed by FAO/AGLW based on analysis for different arid and sub-humid climates. These formula are as follows (3), (4):

$$\text{Effective Rainfall} = 0.6 \times \text{Total Rainfall} - 10 \text{ For (Total Rainfall} < 70 \text{ mm)} \quad (3)$$

$$\text{Effective Rainfall} = 0.8 \times \text{Total Rainfall} - 24 \text{ For (Total Rainfall} > 70 \text{ mm)} \quad (4)$$

Water Use Efficiency (WUE)

WUE is the ratio of plant production (carbon assimilation) per unit of water use and is commonly used to indicate vegetation performance and yield. WUE is calculated by dividing total yield (kg ha^{-1}) by water requirement (m^3) (5).

$$WUE = Y / WR \quad (5)$$

Y = yield (Kg) and WR = water requirement (m^3)

Water footprint calculation

Water footprint concept was studied (blue, gray and green) of orange orchards over the crop growing period for the last 4 years from 2020 to 2023 in five different locations in Egypt. The FAO Penman-Monteith equation method was used to calculate the water requirement of orange productions. For the water footprint concept estimation of the sum of water footprint Green, water footprint Blue and water footprint Gray of orange production, we follow the method of Hoekstra et al. (2011). The water footprint Green, water footprint Blue and water footprint Gray are estimated as follows (6), (7), and (8):

$$WF\ (Green) = \frac{(Pe) \times 10}{Y} \quad (6)$$

$$WF\ (Blue) = \frac{(Etc - Pe) \times 10}{Y} \quad (7)$$

$$WF\ (Gray) = \frac{a \times NAR}{(Cmax - Cnet) \times Y} \quad (8)$$

$$WFT = WF\ Green + WF\ Blue + WF\ Grey$$

WF Green, WF Blue, and WF Gray are the green, blue and gray water footprint measured by unit (m^3 kg^{-1}).

The Pe is the total effective rainfall for orange growth (mm) calculated with the USDA method, Y is the orange yield (kg/ha), α is the leaching runoff fraction, AR is the rate of nitrogen fertilizer use to the field per hectare (kg/ha), CMax is defined as the maximum acceptable concentration (kg/m^3), and CNat is defined as the natural concentration for the pollutants (kg/m^3). The α value is identified as the average of 10% of consumed nitrogen fertilizer under irrigated conditions similar to those applied by Hoekstra et al. (2011). The CMax is 50 mg/L NO_3 or 10 mg/L NO_3- N recommended by the WHO and USEPA, respectively. In this work, the USEPA standard was suggested by Chapagain, et al., (2006) was applied for equation, and the CNat here was supposed to be zero (Chapagain & Hoekstra, 2011).

Statistical analysis

Data obtained from trees at the research sites were analyzed by MSTAT-C package (Freed, 1985) with a probability of 0.05, and differences between means were compared using Duncan’s multiple-range test according to (Wallar & Duncan, 1969).

RESULTS

Citrus are Egypt's most significant fruit crop and the most exported fruit in terms of quantity and significance; therefore, they were chosen for this study. The effect of different fertilizing rates and quantities of irrigation water on tree growth was monitored by determining tree canopy on March 1st and October 1st every season at experimental sites.

Table 2. Effect of tested irrigation rates on tree canopy increment and leaf mineral contents of Navel orange trees during the experimental seasons.

Site	Tree volume increments (%)	N%	P%	K%
First season				
1	34.07A	2.46 A	0.211 B	1.70 A
2	22.24D	2.12 B	0.300 AB	1.4٥ D
3	31.24B	2.25 AB	0.217 B	1.60 B
4	27.00C	2.18 B	0.314 A	1.43 D
5	31.35B	2.32 AB	0.253 B	1.5٤ C
Second season				
1	33.43A	2.41 A	0.241 B	1.64 A
2	14.04D	2.05 B	0.313 A	1.49 B
3	27.26C	2.24 AB	0.260 AB	1.51 B
4	14.85D	2.16 B	0.296 AB	1.47 B
5	31.44B	2.30 AB	0.258 AB	1.54 B
Third Season				
1	24.79C	2.25 AB	0.277 AB	1.48 B
2	22.55D	2.22 AB	0.287 AB	1.40 B
3	15.41E	2.13 B	0.306 A	1.41 B
4	32.33B	2.40 A	0.239 B	1.61 A
5	35.42A	2.45 A	0.229 B	1.66 A
Fourth season				
1	38.08 B	2.36 AB	0.241 B	1.63 A
2	29.03 E	2.13 B	0.306 A	1.42 B
3	33.15 C	2.45 A	0.263 AB	1.76 A
4	30.46 D	2.40 A	0.311 A	1.43 B
5	42.21 A	2.46 A	0.270 AB	1.71 A

*Values in the same column followed by the same letter(s) do not significantly differ from each other according to Duncan's multiple range test at 5% level. *Site1: Al-Shorouk; Site2: Nubaria; Site3: El-Mahalla El-Kubra; Site4: Ashmoun; Site5: Salhyia.

Data in Table 2 shows that canopy increase varied between different sites. The highest canopy ratio increment (42.21%) was recorded in Site 5 (Salhyia) region in the last season, followed by Site 1 (38.08 %) Al-Shorouk region, in (2023), while, trees in Site 2 Nubaria region had the lowest increment ration (14.04%) in (2021).

Estimating mineral elements in the leaves, show a large variation in available nutrients in leaves through the investigation, i.e. N % (2.46 to 2.05 %), P % (0.314 to 0.211%), and K % (1.76 to 1.40 %). These variations were statistically highly significant compared to the tree responses to different N fertilizing averages and irrigation water quantities.

Data presented in Table 2 indicated that the tree that was grown in Nubaria (site 2) fertilized with 353 N units/ha and received 10,320 m^3/ha water in the second season had the lowest N leaf content (2.05 %) during the experiment. On the contrary, trees grown in Salhyia site (5) received 425 N units/ha with (11,880 m^3/ha) of irrigation water, recording the highest N leaf content (2.46 %) during the experiment.

Data in hand Table 2 showed that the highest leaf K content (1.76%) was observed in the last season of the tree grown in the Al Mahalla El Kubra region, fertilized with 425 N units/h and irrigated with 10,320 m^3/ha, followed by trees grown in Salhyia region and received the same N quantity (425 unit/ha) but watering with 11,880 m^3 water/ha. Trees grown in El-Nubaria district that received 386 N units/ha and irrigated with 10,800 m3 water/ha, recorded the lowest K values (1.40 %) in the third season.

Concerning the effect of various irrigation rates and applied N units on P leaf content data in Table 2 cleared that the highest P leaf content (0.314 %) was recorded in trees growing in Ashmoun district and received 9,120 m^3 water and fertilized with 389 N units/hectare in the first season. The minimum P leaf content (0.211 %) was recorded in Al-Shorouk region whereas trees were fertilized with 432 N units and watered by 10,560 m^3/ha in the same season.

There are variations in tree yield according to the quantity of irrigation water and nitrogen fertilizer rates at different experiment sites, ranging from 132.00 to 78.00 kg/tree, as shown in Table 3. The maximum tree yield (132.00 kg/ tree) was recorded in the last season from trees grown in Salhyia region, which received 425 N units/ha and irrigated with 11,100 m^3/ha. The lowest tree yield (78.00 kg/tree) was recorded in site 2 in the second season and site 3 during the third season.

Total yield (Ton/ha) had the same trend, whereas using 425 N units with 11,100 m^3/ha irrigation water in site 5 produced the maximum yield (52.80 tons/ha). On the contrary, Trees grown in sit 2 have a minimum total yield (31.20 tons/ha) was recorded in site 2 in the second season and site 3 in the third one.

The study demonstrated that irrigation water quantities and nitrogen rates affected productivity, and the following ranking was observed for total yield: site 5 > site 1 > site 4 > site 2 > site 3.

Outcome data from Table 3 revealed that the quantity of irrigation water and fertilizing rates in different experimental sites affected fruit quality parameters. TSS/acidity is one of the main maturity indexes for citrus fruits reducing acidity and the accumulation of soluble solid determining fruit maturity according to variety.

The quantity of irrigation water and N rate caused a variation in TSS. The highest TSS rate (11.93) was recorded in site 3, whereas the trees were fertilized by 361 N units and irrigated with 9,360 m^3/ha in the third season. Trees grown in site 2 that were watered by 9600 m^3/ha and received 350 N units/ha recorded the lowest TSS value (11.23).

Table 3. Effect of the tested irrigation rates on tree yield (kg/tree), yield (Ton/ha), and internal fruit quality parameters of Navel orange trees during experimental seasons.

Site	Tree yield (kg/tree)	Yield (Ton/ha)	TSS	Acidity %	TSS/Acid ratio	vitamin C (mg/100g)
First season						
1	96.00 B	38.٤0 B	11.60 A	1.087 A	10.68 A	42.33 A
2	84.00 D	33.60 B	11.23 C	1.060 A	10.60 A	42.07 A
3	84.00 D	33.60 B	11.33 BC	1.053 A	10.77 A	42.83 A
4	89.25 C	35.70 B	11.58 AB	1.107 A	10.55 A	42.60 A
5	108.00 A	43.20 A	11.43 ABC	1.043 A	11.05 A	42.43 A
Second season						
1	102.00 B	40.٨٠ B	11.67 A	1.023 A	11.48 A	42.70 A
2	78.00 C	31.20 C	11.47 BC	1.030 A	11.14 A	42.40 A
3	81.00 C	32.40 C	11.58 ABC	1.053 A	11.04 A	40.33 B
4	84.00 C	33.60 C	11.27 C	1.000 A	11.43 A	42.33 A
5	120.00 A	48.00 A	11.63 AB	0.990 A	11.75 A	41.50 AB
Third season						
1	102.00 B	40.٨٠ B	11.57 B	1.037 BC	11.16 B	41.87 A
2	90.00 BC	36.00 C	11.68 AB	1.070 BC	10.94 B	42.03 A
3	78.00 C	31.20 C	11.93 A	1.133 A	10.54 C	41.00 A
4	90.00 BC	36.00 C	11.27 C	1.087AB	10.38 C	41.00 A
5	126.00 A	50.40 A	11.82 AB	1.020 C	11.59 A	40.97 A
Fourth season						
1	120.00 A	48.00 AB	11.75 A	1.023 A	11.48 A	40.47 A
2	102.00 B	40.80 C	11.59 AB	1.053 A	11.00 BC	40.69 A
3	96.00 B	38.40 C	11.51 B	1.073 A	10.72 C	42.07 A
4	1087.00B	43.20 BC	11.55 AB	1.070A	10.82 C	40.70A
5	132.00 A	52.80 A	11.60 AB	1.030 A	11.27 AB	40.53 A

Note: Values in the same column followed by the same letter(s) do not significantly differ from each other according to Duncan's multiple range test at 5% level. *Site1: Al-Shorouk; Site2: Nubaria; Site3: El-Mahalla El-Kubra; Site4: Ashmoun; Site5: Salhyia.

A higher acid content frequently results in lower-quality orange fruit, whereas a moderate acid amount improves flavor. The difference in acid content was observed among the five sites, results indicated that the lowest acidity value (0.990 %) was recorded in the second season from trees growing in Salhyia. In contrast, the highest acidity ratio (1.133%) was recorded in El-Nubaria district in the third season. Our study showed that N fertilization benefits fruit sugar accumulation and positively affects TSS and VC concentrations, but significantly negatively affects acid content. The effect of various fertilizing rates and quantity of irrigation water in different experimental sites, affect TSS/Acid ratio. The highest TSS/Acid ratio value (11.75) was recorded from trees growing in Salhyia in the second season. The trees growing in Ashmoun district had the lowest TSS/Acid ratio (10.38) in the second season. Vitamin C (ascorbic acid) is one of the most vital water-soluble vitamins and is naturally produced in various fruits and vegetables. Results in hand implied that a high N dose might stimulate VC accumulation in fruit. Regarding VC content in fruit juice, data in Table 3 cleared that, the highest value (42.83 mg/100g) was recorded in site 3 in the third season, and trees growing in site 2 had the lowest VC content (40.12 mg/100g) in the third season.

Regarding the effect of various irrigation rates and applied N units on yield efficiency (Kg/m^3) Figure 1 showed that, the highest yield efficiency (5.92) was recorded in the second season from trees grown in Salhyia district that received 425 N units and watering with 11,10 m^3 water/ ha. On the contrary, the lowest yield efficiency (4.01) was in site 3 in the third season, when trees received 361 N units and 9,360 m^3 water/ ha.

The Water footprint and water use efficiency at Al-Shorouk, north of Tahrir –Beheira presented in Table 4 data shows that water use efficiency ranged from 3.58 to 3.78 kg orange /m^3 water with an average for four years of 3.70 kg orange /m^3 water. The green water footprint ranged from 5 to 122 m^3 water /ton orange depending on rainfall in different years. The blue water footprint was lower in 2020 with a value of 122 m^3 water /ton orange and higher in 2023 with a value of 261 m^3 water /ton orange with an average for four years of 232 m^3 water /ton orange. The gray water footprint was higher in 2020 with a value of 117m^3 water /ton orange and lower in 2023 with a value of 94 m^3 water /ton. The grey water footprint of orange average for four years of 105 m^3 water /ton orange. The average water footprint for Al-Shorouk was 370 m^3 water /ton orange.

The Water footprint and water use efficiency at Nubaria-Beheira presented in Table 4 data shows that water use efficiency was lower in 2021 with a value of 3.02 kg orange/ m^3 water and was the height in 2020 with a value of 3.50 Kg orange / m^3 water. The average of water use efficiency for Nubaria was 3.31m^3 kg orange /m^3 water. The green water footprint ranged from 8 to 127 m^3 water /ton orange depending on rainfall in different years. The blue water footprint was lower in 2020 with a value of 159 m^3 water /ton orange and higher in 2021 with a value of 323 m^3 water /ton orange with an average of four years of 261 m^3 water /ton orange. The gray water footprint ranged from 88 to 118 m^3 water /ton orange. The average gray water footprint was 106m^3 water /ton orange. The water footprint was lower in 2022 with a value of 382m^3 water /ton orange and higher in 2021 with a value of 448m^3 water /ton orange with an average of four-year 402 m^3 water /ton orange. Date in Table 4 presented the Water footprint and water use efficiency at Mahalla al-Kubra- Gharbia data showed that water use efficiency was lower in 2022 with a value of 3.33 kg orange /m^3 water and was height in 2023 with a value of 3.72 kg orange /m^3 water. The average of water use efficiency was 3.57 m^3 kg orange /m^3 water. The green water footprint ranged from 8 to 138 m^3 water /ton orange depending on rainfall in different years with an average of 54 m^3 water /ton orange. The blue water footprint was lower in 2020 with a value of 143 m^3 water /ton orange and higher in 2022 with a value of 280 m^3 water /ton orange. The average blue water footprint was 226 m^3 water /ton orange. The lowest gray water footprint was 118 m^3 water /ton orange and the highest was 170 m^3 water /ton orange. The average gray water footprint was 146 m^3 water /ton orange. The average for Mahalla al-Kubra was 429 m^3 water /ton orange. The water footprint was lower in 2022 with a value of 398 m^3 water /ton orange and higher in 2020 with a value of 478 m^3 water /ton orange.

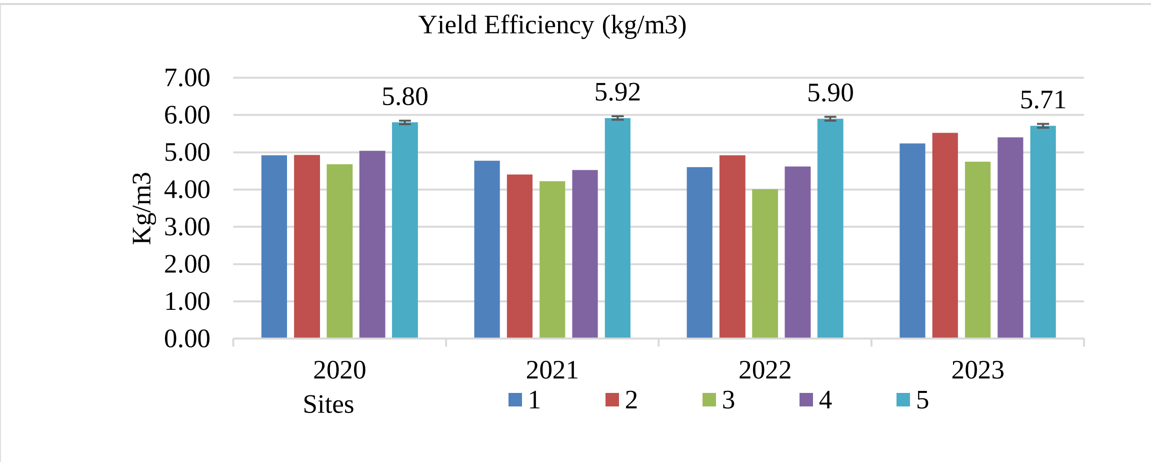

Fig. 1. Yield efficiency (Kg/m3), as affected by the tested irrigation rates on Navel orange trees in different experimental sites. *Site1: Al-Shorouk; Site2: Nubaria; Site3: El-Mahalla El-Kubra; Site4: Ashmoun; Site5: Salhyia.

Table 4. Navel orange water use, water use efficiency, green water, blue water, gray water, and total water footprint for various sites during the experimental seasons.

Year	Yield (ton/ ha)	WU (m^3/ha)	WUE (Kg/m^3)	WF_{green} (m^3/ton)	WF_{blue} (m^3/ton)	WF_{grey} (m^3/ton)	WF (m^3/ton)
Al-Shorouk,							
2020	38.4	10560	3.64	122	153	117	392
2021	40.8	10800	3.78	6	259	108	373
2022	40.8	11400	3.58	24	256	100	356
2023	48.0	12720	3.78	5	261	94	359
mean	42	11370	3.70	39	232	105	370
Nubaria							
2020	33.6	9600	3.50	127	159	107	393
2021	31.2	10320	3.02	8	323	118	448
2022	36.0	10800	3.33	31	273	109	382
2023	40.8	12000	3.40	6	290	88	384
mean	35.4	10680	3.31	43	261	106	402
Mahalla							
2020	33.6	9423	3.56	138	143	170	478
2021	32.4	8880	3.65	50	224	147	421
2022	31.2	9360	3.33	19	280	118	398
2023	38.4	10320	3.72	8	262	149	419
mean	33.6	9496	3.57	54	227	146	429
Ashmoun							
2020	36	9120	3.95	83	170	111	365
2021	33.6	9360	3.59	28	250	114	393
2022	36	9840	3.66	15	260	123	382
2023	43.20	10320	4.18	2	237	93	332
mean	37.2	9660	3.85	32	229	110	368
Salhyia							
2020	43.2	10800	4.29	0	233	97	330
2021	48	10560	4.45	0	220	90	310
2022	50.4	11100	4.54	0	220	92	312
2023	52.80	11880	4.44	0	225	79	304
mean	48.6	11085	4.43	0	225	90	314

The Water footprint and water use efficiency at Ashmoun –Menoufia obtainable in Table 4 data revealed that water use efficiency was ranged from 3.59 to 4.18 kg orange /m^3 water with average for four years 3.85 kg orange /m^3 water. The green water footprint was ranged from 2 to 83 m^3 water /ton orange depend on rainfall amount. The blue water footprint was lower at 2020 with value 170 m^3 water /ton orange and higher at 2022 with value 260 m^3 water /ton orange with average for four years 229 m^3 water /ton orange. The gray water footprint was higher in 2022 with value 123 m^3 water /ton orange and lower in 2023 with value 93 m^3 water /ton orange with average for four year 110 m^3 water /ton orange. The average of water footprint for Ashmoun was 368 m^3 water /ton orange.

The water footprint and water use efficiency at Al-Shorouk, located north of Tahrir-Beheira, as shown in Table 4 data indicates that water use efficiency varied from 3.58 to 3. 78 kg orange/m3 water, with an average over four years of 3.70 kg orange/m3 water. The green water footprint varied from 5 to 122 m^3 water/ton orange, depending on the rainfall in various years. The blue water footprint was lower in 2021 and 2022 with a value of 220 m^3 water /ton orange and higher in 2020 with a value of 233 m^3 water /ton orange with an average for four year 225 m^3 water /ton orange. The gray water footprint ranged from 79 to 97 m^3 water /ton orange. The average gray water footprint was 90 m^3 water /ton orange. The water footprint was lower in 2023 with a value of 304 m^3 water /ton orange and higher in 2020 with a value of 330 m^3 water /ton orange with an average of four years 314 m^3 water /ton orange. Table 5 presented the Water footprint and water use efficiency under surface and drip irrigation data showed that water use efficiency was lower in surface irrigation with a value of 3.71 kg orange /m^3 water and was in height drip irrigation with a value of 3.81 kg orange /m^3 water.

The green water footprint under drip irrigation was 27.3 m^3 water /ton orange and was higher under surface irrigation at 43m^3 water /ton with an incensed percentage of about 63%. The blue water footprint under surface irrigation was 228m^3 water /ton orange and under drip irrigation were 239.3 m^3 water /ton orange. The water footprint was lower under the drip irrigation system with a value of 362 m^3/ton than the surface irrigation system with a value of 398.5 m^3/ton.

Furthermore, Figure 2 shows the comparison between surface and drip irrigation systems for water footprint component data revealed that the drip irrigation system is lower in green, gray and total water footprint than surface irrigation. The blue water footprint was the height under drip irrigation system than surface irrigation system.

Table 5. Navel orange yield, water use, water use efficiency, green water, blue water, gray water, and total water footprint under drip and surface irrigation.

Site	Drip irrigation				Surface irrigation		
	1	2	5	Mean	3	4	Mean
Yield (ton/ha)	42	35.4	48.6	42	33.9	37.2	35.5
WU (m^3/ha)	11370	10680	11085	11045	9496	9660	9578
WUE (Kg/m^3)	3.7	3.31	4.43	3.81	3.57	3.85	3.71
WF_{green} (m^3/ton)	39	43	0	27.3	54	32	43
WF_{blue} (m^3/ton)	232	261	225	239.3	227	229	228
WF_{grey} (m^3/ton)	105	106	90	100.3	146	110	128
WF (m^3/ton)	370	402	314	362	429	368	398.5

*Site1: Al-Shorouk; Site2: Nubaria; Site3: El-Mahalla El-Kubra; Site4: Ashmoun; Site5: Salhyia.

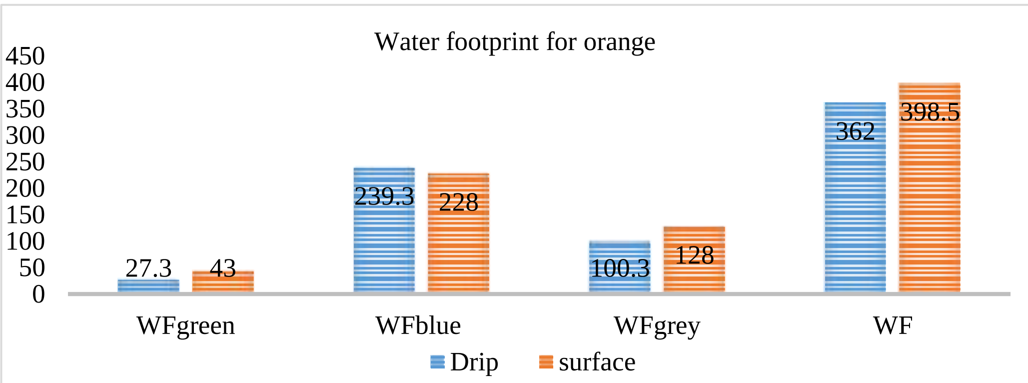

Fig. 2. The mean of green water footprint, blue water footprint, gray water footprint, and total water footprint under drip and surface irrigation for Navel orange.

DISCUSSION

This study investigates the Water Footprint components and water use efficiency of Navel Orange trees at five different locations in Egypt during 2020–2023. It is well documented that water is one of the limiting factors in the fruiting and productivity of fruit trees and affects plant metabolism. Various irrigation practices are used in citrus orchards in Egypt, including reduced water and N manual application), including reduced water and N fertilizer input, increased water productivity (WP) and water use efficiency (Li et al., 2021).

Our results indicate that the productivity of citrus orchards using drip irrigation may be significantly higher than that under surface irrigation and manual N fertilization. There are different responses to water quantity under experimental sites conditions on tree yield and fruit quality parameters, in addition, nitrogen levels significantly affect total fruit yield and fruit characters. There is a positive correlation between the availability of water and nitrogen in the soil during the growth cycle and productivity (Fikry et al., 2022; Panigrahi & Srivastava, 2016).

Increasing water availability improves the growth and productivity of fruit trees. The highest tree volume increment was in site (5) in the fourth season when trees were irrigated with 11,880 m^3 and fertilized with 425 N units.

Our findings in agree with (Rakha et al., 2024; Liao et al., 2019) who reported that high N fertilizers increase the total acidity of citrus fruit juice and reduce TSS/Acidity and vitamin content.

Our study indicated that moderate irrigation water with moderate N fertilizers in clay soil increases TSS in fruit juice. While in sandy soil with high irrigation and a high N rate, the TSS/Acidity ratio increased. Furthermore, acidity increased with increasing nitrogen rate, this could be due to the limited differences in nitrogen levels between the study sites. These results indicated that nitrogen fertilization treatments provided adequate nutrition and increased acidity (Liao et al., 2019).

Mekonnen and Hoekstra's model serves as an effective way to compare water footprints for crops grown worldwide. When comparing crop water footprint numbers, it is important to note the impact of crop yields on water footprint. Due to the role of yields in determining water footprints, these values are influenced by the different factors that impact yields apart from water availability, including nutrient source, crop varieties, farmer access to agricultural inputs, the severity of rainfall, soil type and condition and pest and disease incidence. Water appropriation can differ depending on the region, climate conditions (rainfall and evapotranspiration), the irrigation methods used (surface, or drip), and the fertilizers amount and pesticides allowed. The water consumption depends on crop characteristics, especially the tree age and fruit yield (Mekonnen & Hoekstra, 2014). Especially in arid and semi-arid regions, the amount of irrigation water plays numerous roles in the productive yield of oranges by affecting the yield and water use efficiency. Therefore, good irrigation management is required for maximum quality yield in citrus (Zekri, 2000).

The water use efficiency increased with micro-sprinkler irrigation systems under 80% ETc, which resulted in 2.57 and 2.67 kg of fruit per cubic meter of irrigation water needed in the first and second seasons, respectively (Youssef et al., 2023). In addition, water productivity or water use efficiency for oranges ranged from 3.6 to 3.0 kg m-3 and decreased with increasing irrigation water applied (Hammami & Mellouli, 2011).

Green water talks about to the precipitation on soil that does not run off or recharge the groundwater but is stored in the soil or temporarily stops on top of the soil or vegetation. The green water can also leave the soil through evaporation or subsurface runoff, but it is considered productive only when used for plant transpiration. The lower green water footprint is expected in our study due to the semi-arid climate of Egypt and depends on rainfall amounts for different locations in this study. The share of green water footprint is low in the total OF, which concludes that the share of effective rainfall is very low. The green water footprint is related to effective precipitation. Since the effective rainfall Peff is low in the extra-arid regions, hence the share of green water footprint is lower than the other water footprint components (Sun et al., 2012).

The blue water footprint is a role of the consumptive irrigated water amount and the produced yield (Mekonnen & Hoekstra, 2020).·Blue water footprint is related to the use of irrigation water (net water requirement). Irrigation water is a vital element of improving plant productivity and minimizing the yield gap, mainly in arid regions with severe water scarcity. The water consumed by different irrigation techniques (surface and drip) and irrigation strategies were not the same? The blue water footprint indicates the amount of potable water contributed to a process and/or product, it will be high in agriculture. This result matches Bazrafshan et al. (2018) who reported that the high water requirement and low yield per area have led to a high blue water footprint.

The greywater footprint is defined to the use of freshwater to dilute the pollutants (nitrogen fertilizers) when the nitrogen fertilizer amount was incensed the graywater footprint increased.

Increased use of nitrogen fertilizer has both positive and negative effects. The rise in crop yields production over the past decades is partly due to the increased use of fertilizer in agriculture. However, a large fraction of nitrogen used to croplands in the form of fertilizer and manure ends up entering the freshwater system causing degradation of the water quality. The Grey Water Footprint focuses on the release of nitrogen to freshwater systems and translates the nitrogen load into a volume of water to assimilate. These results agree with Tozzini et al. (2021) who show that the quantity of nitrogen fertilizer was the main factor that affected greywater footprint and that increasing nitrogen fertilizer dosage can increase greywater footprint values.

The mean source of freshwater contamination affected by fertilizers and surface run-off of nitrogen Pollution levels are determined by a variety of factors, including soil texture, terrain, and, most importantly, crop and farm management (Delin & Stenberg, 2014). The water footprint under study condition was 362 m^3/ton (0.362 m^3/kg) under the drip irrigation system and the surface irrigation system with a value of 398.5 m^3/ton (0.398 m^3/kg), this result agreed with (Arabi-Yazdi et al., 2009) who reported that the weighted average of citrus WFT is 0.36 m^3/ kg in Iran. In addition, previous work reported that the average world water footprint for oranges is about 510 m^3/ton (0.510 m^3/kg), according to (Mekonnen & Hoekstra, 2014).

CONCLUSION

Results showed that using 11085 m3/ha in Salhyia district produced maximum yield and improved most fruit quality parameters. Moreover, water use efficiency in drip irrigation (3.81 kg orange/m3 water) was better than surface irrigation (3.71 kg orange/m3 water). Regarding water footprint components, data revealed that the drip irrigation system is lower in green, gray and total water footprint than surface irrigation. The blue water footprint was the height under the drip irrigation system rather than the surface irrigation system. This work provides practical approaches for researchers and policymakers in the agriculture area to manage the water footprint and optimize the water consumption and productivity of Navel oranges in Egypt.

Conflict of interest

The authors declare that there is no conflict of interest**.**

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