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Water footprint of lettuce production in aquaponic and hydroponic systems

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Abstract

Sustainable agriculture allows the efficient use of natural resources, particularly water. This study aimed to compare the water footprint of the lettuce (*Lactuca sativa* L.) cultivation in two production systems: aquaponic and hydroponic, in order to understand its impact on water resources. Both production systems were established in a shade house in the state of Sonora, Mexico. The experiment was conducted from May 20 to July 29, 2020. The estimation of the WF_{total} was calculated by adding the blue water footprints, consumption of water sheet in the development of the crop and of the inputs and materials used in each system (based on information from the scientific literature). The results indicated an average harvested lettuce weight of 0.056 kg (±0.005 kg) in the aquaponic system and 0.097 kg (±0.007 kg) in the hydroponic system. The statistical analysis was evaluated with the Student's t-test with a significance level of 5%. The estimated BWFs were 0.2941 and 0.1721 $m^3\ kg^{-1}$, the WF_{total} were 2.6841 $m^3\ kg^{-1}$ and 0.1821 $m^3\ kg^{-1}$ for the aquaponic system and hydroponic system, respectively, for 19 plants in each system. The values of the WF_{total} were high since they represent the sum of the blue water footprints and the $WF_{inputs\ and\ materials}$. The results of this research confirmed the hypothesis proposed as the aquaponic system registered a greater water footprint. However, it is advisable to generate more knowledge on the subject.

Palabras clave:

growing room, NTF system, sustainable agricultural techniques, tilapia.

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Introduction

The water footprint (WF) is an indicator of the total volume of freshwater that is used directly and indirectly to produce a good or service (Oltra and Melgarejo, 2020) and expresses the pressure and environmental impacts that productive activities exert on water resources. WF is a tool for biodiversity conservation and analysis for sustainability (Shi *et al*., 2017) driven by increasing demand, scarcity, and degradation of water quality.

The WF of the agricultural sector establishes guidelines for the use and integrated management of water (Zárate *et al*., 2017) in public policy and in scientific research. Agricultural WF represents 86%of humanity's WF (Hoekstra and Chapagain, 2008) and measures the WF of the product's supply chain: cultivation, processing, manufacturing, transportation, and sale of the product (Martínez, 2013).

WF is made up of: blue WF (BWF), which is the volume of fresh water for crop irrigation, it is associated with water deficit and quality; green WF (GWF), it is the volume of rainfall that plants store and consume (evapotranspiration), so it is used by the crop; grey WF (GrWF), it is the volume of water needed to dilute pollutants (agrochemicals) until they are harmless (Hoekstra and Mekonnen, 2011), only considers the waste stream of the most critical pollutant to water bodies, and values part of the agrochemicals used (Hoekstra *et al*., 2011).

Aquaponic (AS) and hydroponic (HS) systems represent new forms of production with a lower environmental impact (Wilson, 2018). AS combines aquaculture with hydroponics and has advantages (low operating costs, less use of agrochemicals, reuse of water in the system and value-added plant productivity) over traditional agricultural systems (TAS), although it has limitations, it depends on electricity for the operation of water and aeration pumps and the ecological complexity that risks the system in the event of any failure (such as the correct density of microorganisms, fish, and plants).

On the other hand, the vegetable HS uses two techniques: floating root and NFT (Nutrient Film Technique): in the first, the vegetable grows directly on water, with the nutrient solution dissolved in it and without substrate, with the NFT technique, the plant grows on a sheet of water in continuous movement enriched with nutrient solutions. The HS requires 82 times more energy than a TAS, but 92% less water and produces 11 times more yield per area (Barbosa *et al*., 2015).

Lettuce is a popular vegetable on a global scale; Mexico was the ninth producer in 2019 and 2020 (SADER, 2019) with 516 000 and 539 000 t, respectively (SIAP, 2021). In 2019, Baja California, Puebla and Sonora were the states with the largest harvested area, but Sonora had the highest yield (SIAP, 2019). In 2017, this crop became one of Sonora's main agricultural export products with 10 241 t (SAGARHPA, 2018).

The objective of the research was to estimate the water footprint of lettuce (*Lactuca sativa* L.) cultivation in aquaponic and hydroponic systems to determine the impact on water resources compared to the conventional production system and to generate knowledge on the subject. The hypothesis was that the aquaponic system has a larger water footprint than the hydroponic system.

Materials and methods

The study was carried out in the nursery of the Department of Agriculture and Livestock of the University of Sonora, Mexico, at the geographical coordinates 29° 00' 47" north latitude and 111° 08' 13" west longitude, at an altitude of 151 m. The climate of the region is BW(h') hw (x') (e'), characterized by an average annual temperature of 25 °C and an annual rainfall of 246.4 mm (García, 2004). The experiment was conducted from May 20 to July 29, 2020, and comprised the following stages.

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Stage I: establishment of aquaponic and hydroponic systems

The work was carried out in a shade house covered with a woven mesh of 20 x 10 threads in 1 cm^2 (300 microns) of crystal color. Two holes, 70 cm in diameter and 80 cm deep, were made in the ground inside the shade house. A 250 L capacity Rotoplas® water tank was introduced in each of them, one for the AS and one for the HS. The ground around the water tank was covered with white gravel in order to reflect the beams and prevent the absorption of heat. For water recycling, an 800 L h^{-1} Airon® pump and a 1 HP 110 V 11.6 A single-phase blower were used in each of the production systems.

A biofilter made of 1 m of high-density polyethylene (HDPE) material, corrugated, cut into pieces, and stored in a 20 L bucket, was placed in the AS. Then, the nitrifying microorganisms were integrated, and the recycling of the water began on May 20. Concentrations (ppm) of ammonium (NH_3), nitrites (NO_2^-) and nitrates (NO_3^-) were measured daily (in triplicate) with an API master test kit according to the kit's instructions, from 5 ml samples.

Once the maturity of the biofilter with the presence of the nitrifying bacteria was determined, three Nile tilapia (*Oreochromis niloticus* L.) with an initial weight of 500 g each were introduced, which were fed with commercial kibble for developing fish, 3.5 mm (Nutripec brand) enriched with proteins (32%) and fats (6%).

Stage II: lettuce crop development and yield

This stage began on May 20, 2020. The germination of the seed took place in an agricultural growing room under controlled environmental conditions: temperature of 25 °C, relative humidity of 51% (measured with a Taylor thermohygrometer), artificial lighting provided by a 1.2 m long blue (470 nm) and red (625 nm) horticultural lamp of the Arize™ life brand.

The seed was sown in a rockwool substrate in an extra rigid flat tray with an area of 55 x 28 cm (GLL brand, model CH00). The seeds were hydrated with a dosed irrigation of 2.47 L in total, for the following 37 days (time needed for germination) from sowing. On June 26, 19 lettuce seedlings were transplanted into the PVC pipes of each of the systems. The infrastructure of the AS and HS had dimensions 3.0 x 0.5 m, the cultivation area was 1.5 m^2 (Figures 1 and 2).

Figure 1. Hydroponic lettuce production system.

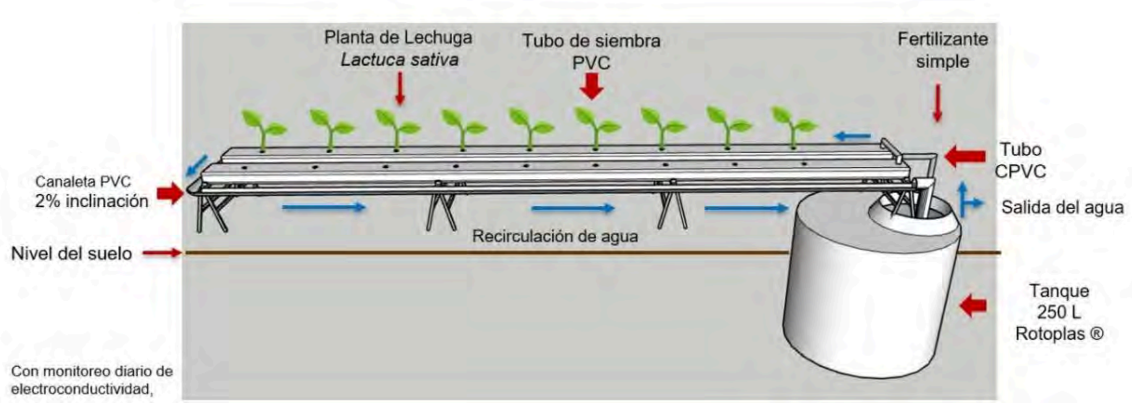
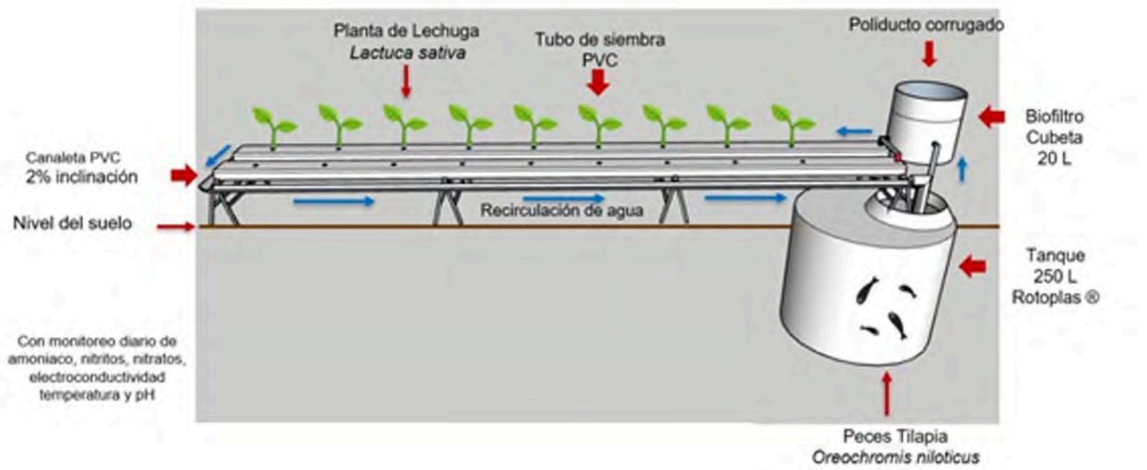


Figure 2. Aquaponic system in lettuce production.



During the development of the crop in the HS, a hydroponic fertilizer of the Hort Americas brand (9-7-37 ratio N-P_2O_5-K_2O) and nitric acid (HNO_3 at 3%) were used to maintain the pH in a range of 6.5-7.6, which is an adequate range (between 6.5 and 8.5) according to Somerville *et al*. (2022). The lettuce harvest took place on July 29, 2020. In the production of AS and HS, plant weight (kg) and yield (kg m^{-2}) were considered. Their average values were compared with the Student's t-test with a significance level of 5% in the Excel program of Windows, Version 10.

Stage III: water footprint of lettuce cultivation in aquaponic and hydroponic systems

The total WF was calculated using the 'Step-wise accumulative' approach, this means that the WF of a product was determined according to the WF of the inputs of each production activity, plus the WF of the whole process (Hoekstra *et al*., 2011). Therefore, the WF of lettuce cultivation in the AS and HS were determined:

$$WF_{total}= WF_{installation}+ WF_{yield}$$

1). In order to obtain the environmental impact expressed in the $WF_{installation}$, a list of all the inputs and materials used in each system was previously made. These were weighed with a Ohaus defender 3000 digital scale (sensitivity 58 - 0.09 kg). The $WF_{installation}$ was calculated using equation 2.

$$WF_{installation}=\sum\left[\left(\frac{WF_{inputs\ and\ materials} * w}{yield}\right)*F_{ls}\right]$$

2). Where: the $WF_{inputs\ and\ materials}$ (m^3 kg^{-1}) refers to the WF of the inputs and materials used in each system (values consulted in the scientific literature); w= is the weight (kg) of the materials; yield= is the total weight of the lettuce; and F_{ls}= (one-dimensional) is the lifespan factor of materials (such as PVC pipes and HDPE water tank), which relates their lifespan (or service time) to the cultivation period from transplanting to harvest (34 days). Thus, the $WF_{installation}$ related to the lettuce cultivation cycle was obtained.

The WF_{yield} includes the volumes of water from: rainfall in the open field, water contaminated in the production process and those used by the crop (equation 3):

$$WF_{yield}= GWF+ GrWF+BWF$$

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3). Where: GWF= green water footprint; GrWF= grey water footprint; and BWF= blue water footprint. However, GWF (no rainfall beyond the shadow house) and GrWF (without evaluations of agrochemical WF at the beginning and end of the experiment) were excluded in the calculation of WF_{yield} of the present study.

Therefore, WF_{yield} in this study was similar to BWF. This was assessed for non-conventional systems according to equation 4:

$$BWF=\frac{WG+CW+AW}{\gamma}$$

4). Where: BWF= is the blue WF: aquaponic and hydroponic; WG= water for germination; CW= is the circulating water in the system; AW= is the added water (irrigation sheet, m); (= is the mass produced per surface area (kg m^{-2}). Once the $WF_{inputs\ and\ materials}$ and the WF_{yield} (= BWF) were obtained, the WF_{total} was calculated using equation 1.

Results and discussion

Lettuce crop development and yield (stage II

In each production system, 12 heads of lettuce were harvested per m^2 of planting, the yield obtained was double compared to the TAS, where six to eight lettuces are produced in 1 m^2 due to the spaces between the irrigation canals. The total weight of the crop (in 1.5 m^2= 19 heads of lettuce) was 1.08 kg in the AS and 1.85 kg in the HS, while the average plant weights were 0.056 kg (±0.005) and 0.097 kg (±0.007), respectively.

The Student's t-test showed a significant difference ($p\leq$ 0.05) between the average weights recorded in each system. Yields were 0.72 and 1.23 kg m^{-2} in the AS and HS, respectively, which represented a higher yield (58.37%) in the HS than in the AS. The HS produced plants with a weight higher than the AS (97 and 56 g $plant^{-1}$), contrary to what was reported by Delaide *et al*. (2016), who indicated a weight in the AS plants higher than those in the HS.

This was attributed to the fact that this study was carried out under elevated room temperature (30 to 40 °C) and water conditions (30 to 37 °C), higher than the ranges managed by Delaide *et al*. (2016) and those suggested by Portillo *et al*. (2020) for the optimal development of the crop (15 to 20 °C). It was estimated that the high water temperature in the AS affected the metabolism of the fish and reduced their feeding rate, which provided less nutrients for plant growth and production in the AS compared to the HS.

Monsees *et al*. (2019) recorded a yield 32% lower than the average value due to water temperature (29 °C): they reported differences in lettuce weight, leaf number and head leaf area between HS and AS. Lennard and Ward (2019) highlighted that high temperatures (>2 °C) and NFT systems have low levels of oxygen dissolved in water (<5 ppm), this affects tilapia feeding as they stop eating and producing nitrogenous compounds (necessary for the development of lettuce). Therefore, it was estimated that the water temperature recorded in the present study (30 and 37 °C) was a limiting factor in the nutrient absorption yield of plants.

A nitrate concentration of 80 ppm was detected in this study. NO_3 is the end product of ammonium oxidation by nitrifying bacteria and is less toxic than NO_2 and ammonium that risk the health, survival, and zootechnical performance of fish (González *et al*., 2021). Although NO_3 is present in low levels in ASs because it is the main source of N from plants, Kubitza (2017) suggests amounts between 100 and 200 mg L^{-1} for optimal tilapia growth.

Flores-Aguilar *et al*. (2020) suggest changing water to remove excess nutrients, avoid toxicity, and not risk the health of nitrifying bacteria and tilapia (Valenzuela *et al*., 2017). Somerville *et al*. (2022) noted that the water quality parameters recommended in ASs for optimal fish development are: total ammonia nitrogen, < 2 mg L^{-1} (=1 ppm), nitrite, < 1 mg L^{-1}, dissolved oxygen, > 4 mg L^{-1}, pH between 6.5 and 8.5, temperatures of optimal water 27-30 °C and vital water 14-36 °C.

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In the development of the crop, 0.0675 m^3 of water was added in both systems: in the AS it was to decrease the nitrate content and in the HS it was to counteract the increase generated in the electrical conductivity (2.9 dS m^{-1}) and thus, avoid adverse conditions in the lettuce crop since the roots stop absorbing macro and micronutrients when the water has a high content of mineral salts (Monsees *et al*., 2019).

Water footprint of lettuce cultivation in aquaponic and hydroponic systems (stage III)

The WF_{yield} (=BWF) of AS (0.2941 m^3 kg^{-1}) was higher than that of HS (0.1721 m^3 kg^{-1}) (Table 1), $WF_{inputs\ and\ materials}$ (excluding F_{ls}) had the same ratio (8.1429 and 1.98 m^3 kg^{-1}, respectively) (Table 2). $WF_{inputs\ and\ materials}$ were considered as the 'investment water footprints' of the infrastructure establishment for AS and HS, the values of which included the entire lifespan of inputs and materials. In these cases, the WF_{total} of lettuce cultivation in the AS was 8.437 m^3 kg^{-1} and in the HS, 2.15 m^3 kg^{-1}. However, materials and inputs will be used in more production cycles, so that, when considering the F_{ls}, the WF_{total} of the AS was 2.6841 m^3 kg^{-1} and in the HS of 0.1821 m^3 kg^{-1} (Table 2).

Table 1. Blue water footprint of aquaponic and hydroponic systems.

Process	Sheet (m)	BWF AS (m^3 kg^{-1})	Sheet (m)	BWF HS (m^3 kg^{-1})
Germination stage	0.0008	0.001111	0.0008	0.00065
Crop development	0.045	0.0625	0.045	0.0365
Recirculating water in the system	0.166	0.2305	0.166	0.1349
BWF		0.2941		0.1721

BWF= blue water footprint; AS= aquaponic system; HS= hydroponic system.

Table 2. Water footprint of inputs and materials of aquaponic and hydroponic systems.

Material	Water footprint		Lifespan		F_{LS}	Aquaponic system[*]				Hydroponic system[*]			
	(m^3 kg^{-1})	Source	Years	Source		Material	CV (m^3)	WF without F_{LS} (m^3 kg^{-1})	WF with F_{LS} (m^3 kg^{-1})	Material[¶]	CV (m^3)	WF without F_{LS} (m^3 kg^{-1})	WF with F_{LS} (m^3 kg^{-1})
Fish food	2.25	(Pérez-Rincón *et al*., 2017)		NA		1.14	2.56	2.38	2.38	NA	NA	NA	NA
Bucket and biofilter (HDPE)	0.12[§]	(Haghighi *et al*., 2018)	10	(Sendanayake, 2016)	0.0066	2	0.24	0.23	0	NA	NA	NA	NA
Metal structures	0.7	(Kluender, 2013)	40	(Hernández, 2019)	0.0016	6.9	4.86	4.5	0.01	3.6	2.53	1.37	0
Fertilizer	0.00018	(Tolón *et al*., 2013		NA		NA	NA	NA	NA	0.19	0.034	1.85 E^{-05}	0.18
Air injection hose (HDPE)	0.12[§]	(Haghighi *et al*., 2018)	10	(Sendanayake, 2016)	0.0066	0.06	0	0.01	0	0.06	0	0	0

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Material	Water footprint		Lifespan		F_{LS}	Aquaponic system*				Hydroponic system*			
	(m^3 kg^{-1})	Source	Years	Source		Material	CV (m^3)	WF without F_{LS} (m^3 kg^{-1})	WF with F_{LS} (m^3 kg^{-1})	Material¶	CV (m^3)	WF without F_{LS} (m^3 kg^{-1})	WF with F_{LS} (m^3 kg^{-1})
PVC	0.01	(Wang *et al*., 2019)	5	(Zaman y Newman, 2021)	0.0132	8.2	0.13	0.13	0	8.2	0.13	0.07	0
Polyethylene water tank 250 L (HDPE)	0.12§	(Haghighi *et al*., 2018)	10	(Sendanayake, 2016)	0.0066	7.9	0.97	0.9	0.01	7.9	0.97	0.53	0
WF_{inputs} and materials								8.14	2.39			1.98	0.01
Total WF								8.43	2.68			2.15	0.1821

F_{LS}= lifespan factor (dimensionless); WF with F_{LS}= water footprint calculated with lifespan factor; WF without F_{LS}= water footprint calculated without lifespan factor; NA= not applicable; CV= calculated volume; *= the estimation of the water footprint per kg considered the total production of 1.07 and 1.85 kg for the aquaponic and hydroponic systems, respectively; §= average value of global data; ¶= weight of the material used.

The topic of WF of lettuce crops in AS and HS is under development, so there is little scientific literature that allows us to compare the results obtained in this work. Some theses, such as that of Blandón and Benavides (2020), record the WF of the AS (NFT) of 6.77 L (0.0067 m^3) and the WF with TAS (and daily irrigation) of 63 L (0.063 m^3), in both cases to produce a lettuce plant in a 30-day cycle. The same authors pointed out that in the AS, the weight of lettuce was different: the Auvona variety was valued between 45.4 and 54.06 g, the Batavia variety, between 22.26 and 43.86 g, with no report of lettuce weight in TAS.

Based on the above data, if we consider an average weight of 49.73 g for the Auvona variety and 33.06 g for the Batavia variety, one kg is made up of 20 and 30 heads of lettuce, respectively. If these quantities are multiplied by the WF obtained in that study (6.77 L), WFs of 135.4 L kg^{-1} (0.1354 m^3 kg^{-1}) and 203.1 L kg^{-1} (0.2031 m^3 kg^{-1}) are generated, respectively. This means that the WF_{total} obtained in the present study (2.6841 m^3 kg^{-1}) is 19.82 and 13.22 times higher (Table 3).

Table 3. Water footprint of lettuce cultivation in aquaponic, hydroponic, and traditional systems.

Production system	Country	BWF (m^3 kg^{-1})	GrWF (m^3 kg^{-1})	GWF (m^3 kg^{-1})	TWF (m^3 kg^{-1})	Source
AS/I	India	0.038				(Biswas *et al*., 2023)
AS/ Var. Auvona	Nicaragua	0.213				(Blandón and Benavides, 2020)
AS/Var. Impulsora	Nicaragua	0.0948				(Blando and Benavides, 2020)
HS/Baby size	Chile	0.017	0.0008	0	0.018	(Caro, 2014)
TAS/running water/I	India	0.077				(Biswas *et al*., 2023)
TAS/ running water/I	India	0.026				(Biswas *et al*., 2023)
TAS	Malaysia	0.0511		0.1865	0.2376	(Harun and Hanafiah, 2018)

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Production system	Country	BWF	GrWF	GWF	TWF	Source
			(m^3 kg^{-1})			
TAS		0.1332	0.0758	0.028	0.237	(Mekonnen and Hoekstra, 2011)
TAS/summer	South Africa	0.0313				(le Roux *et al*., 2018)
TAS/autumn	South Africa	0.0512				(le Roux *et al*., 2018)
TAS/winter	South Africa	0.0926				(le Roux *et al*., 2018)
TAS/spring	South Africa	0.0562				(le Roux *et al*., 2018)
TAS	Colombia	0.0884	0.0815	0.105	0.2749	(Orjuela and Vargas, 2016)

AS = aquaponic system; HS= hydroponic system; TAS= traditional agricultural system.

This was attributed to the fact that in the present study, the $WF_{inputs\ and\ materials}$ was considered, while Blandón and Benavides (2020) did not specify the procedure for calculating the WF. The WF of the Auvona variety of the TAS was lower than the WFs obtained in this study (BWF of the AS= 0.2941 m^3 kg^{-1}, BWF of the HS= 0.1721 m^3 kg^{-1}), while the WF of the Batavia variety was higher than the BWF of the HS, but lower than the BWF of the AS.

On the other hand, Caro (2014) determined the WF_{total} of 18 m^3 t^{-1} (0.018 m^3 kg^{-1}) of the 'baby' size Levistro variety (Rijk Zwaan) produced in HS in a greenhouse (BWF= 95.4%, GrWF= 4.6%) when comparing the WF_{total} of said research with the present one (0.1821 m^3 kg^{-1}), it was observed that this was 10 times lower. The author highlighted that the values obtained are underestimated due to omissions of water consumption, which would generate an increase in WF (in nursery plantations and $WF_{inputs\ and\ materials}$, among others). However, the BWF (0.017 m^3 kg^{-1}) reported by Caro (2014) is similar to that of the present study (0.1721m^3 kg^{-1}).

For their part, Biswas *et al*. (2023) determined the WF of lettuce cultivation under AS and in TAS. In the AS, the WF was 38 cm^3 g^{-1} (0.038 m^3 kg^{-1}), which was 70 times lower than the WF_{total} of the present study (2.6841 m^3 kg^{-1}), in the TAS, the WFs with running water and wastewater management were 0.077 and 0.026 m^3 kg^{-1}, respectively. The authors indicated that the reported WFs represent the measure of the total volume of water required to produce a crop, without specifying whether the values correspond only to the BWF.

Other studies in TAS, such as that of Orjuela and Vargas (2016), indicated a WF_{total} of 274.9 m^3 t^{-1} (0.2749 m^3 kg^{-1}) for lettuce (38.2% GWF, 32.2% BWF, and 29.6% GrWF) (Table 3). The WF_{total} of the present study was 9.8 times higher than the previous one, and 3.3 and 1.9 times higher than the BWF of AS and HS, respectively. This was attributed to the fact that the $WF_{inputs\ and\ materials}$ in this study accounted for 89% of the WF_{total} in the AS and 52.5% of the HS. On the other hand, Orjuela and Vargas (2016) only considered the WF of inputs (= GrWF; related to contamination from agrochemicals) and did not consider the WF of materials.

Authors such as Harun and Hanafiah (2018) determined a WF_{total} of 0.2376 m^3 kg^{-1} and an BWF of 0.0511 m^3 kg^{-1} in lettuce in TAS: the WF_{total} of that study is 11 times lower in contrast to the WF_{total} of this research, as well as the BWFs of AS and HS (5.7 and 3.37 times, respectively). For their part, le Roux *et al*. (2018) reported the BWFs in TAS with extreme values, 0.0313 (summer) and 0.0926 m^3 kg^{-1} (winter) (Table 3), the BWFs are lower than those corresponding to the present study.

When comparing the WF_{total} of AS and HS obtained in this study with the previous studies, it was found that these indicated lower values with respect to the present study, in which the 'Step-wise accumulative' approach was used and which integrated the $WF_{inputs\ and\ materials}$ in the calculation of the WF_{total}. Although some of those studies included WF_{inputs} (agrochemicals), they excluded the calculation of $WF_{materials}$ required in AS and HS facilities. These factors, when considered in this

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study, substantially increased the WF_{total} of the AS and HS, since they constituted 89% and 52.5% (respectively) of their value. Baptist *et al*. (2020); Hoekstra and Mekonnen (2011) recorded an WF of 237 m^3 t^{-1} (0.237 m^3 kg^{-1}) for this vegetable in the TAS, which is considered the global average value (Water Foodprint Network, 2016).

When contrasting that WF with the BWF of AS (0.2941 m^3 kg^{-1}) and HS (0.1721 m^3 kg^{-1}) of this work, it was found that these are 1.24 times higher and 0.726 times lower than the former, correspondingly. The BWF of AS is lower than the BWF of other vegetables in the TAS, such as spinach (0.014 m^3 kg^{-1}), broccoli (0.021 m^3 kg^{-1}) and onion (0.044 m^3 kg^{-1}) (Mekonnen and Hoekstra, 2011).

Conclusions

This research determined the water footprint of lettuce (*Lactuca sativa* L.) cultivation in aquaponic and hydroponic systems. The results confirmed the hypothesis proposed as there was a greater water footprint in the aquaponic system. The estimated water footprints were higher compared to similar studies, which is justified by the inclusion of the water footprints of materials and inputs used in the construction of the systems, as part of the chain of the crop's production process. This study contributed to the generation of knowledge on the subject, which is scarce on a global scale.

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Bibliography

1 Barbosa, G.; Gadelha, F.; Kublik, N.; Proctor, A.; Reichelm, L.; Weissinger, E.; Wohlleb, G. and Halden, R. 2015. Comparison of land, water, and energy requirements of lettuce grown using hydroponic *vs* conventional agricultural methods. International Journal of Environmental Research and Public Health. 12:6879-6891.

2 Bautista, D.; Otazo, E.; Román, A.; Pavón, N. y Prieto, F. 2020. La huella hídrica de diferentes cultivos: un panorama global. Revista Latinoamericana el Ambiente y las Ciencias. 11(28):419-422.

3 Biswas, A.; Duary S.; Islam, A. and Bhattacharjee, S. 2023. water footprint and productivity of lettuce with non-conventional water resources biological forum an international journal. 15(4):01-04.

4 Blandón, E. E. y Benavidez, L. E. 2020. Evaluación de dos variedades de *Lactuca sativa* bajo condiciones de acuaponía con las técnicas de canaleta, NFT horizontal vertical. Tesis de licenciatura. Universidad Católica del Trópico Seco. Nicaragua.

5 Caro, L. N. 2014. Estimación de la huella hídrica de la producción de lechugas 'baby' bajo sistema hidropónico. Tesis de licenciatura. Universidad de Chile, Chile.

6 Delaide, B.; Goddek, S.; Gott, J.; Soyeurt, H. and Jijakli, M. 2016. Lettuce (*Lactuca sativa* L. var. Sucrine) growth performance in complemented aquaponic solution outperforms hydroponics. Water. 8(10):467-473.

7 Flores-Aguilar, P.; García-Trejo, J. y Martínez-Guido, S. 2020. Acuaponía: una alternativa versátil e integral en la producción de alimentos para el entorno mexicano. Digital Ciencia@UAQRO. 14(1):43-53.

8 García, E. 2004. Modificaciones al sistema de clasificación climática de Köppen. México, DF. Universidad Nacional Autónoma de México (UNAM).

https://doi.org/10.29312/remexca.v15i3.3304

9 González, O.; González, L.; Comolli, J.; Santinón, J.; Agüero, C. y Roux, J. 2021. Parámetros productivos de dos especies de peces autóctonos (*Piaractus mesopotamicus* y *Prochilodus lineatus*) en un sistema acuapónico con lechuga (*Lactuca sativa* sp). Agrotecnia. 31:43-55. 10.30972/agr.0315815.

10 Haghighi, E.; Madani, K. and Hoekstra, A. 2018. The water footprint of water conservation using shade balls in California. Nature Sustainability. 1:358-360. 10.1038/s41893-018-0092-2.

11 Harun, S. N. and Hanafiah, M. M. 2018. Blue a green water use of cultivating selected crops in Malaysia. AIP Conference Proceedings. 10.1063/1.5027942.

12 Hernández, S. 2019. Degradación y durabilidad de materiales y componentes constructivos. México, DF. Universidad Nacional Autónoma de México (UNAM).

13 Hoekstra, A. Y. and Chapagain, A. K. 2008. Globalization of water: sharing the planet's freshwater resources. Oxford, UK. Willey-Blackwell.

14 Hoekstra, A. Y. and Mekonnen, M. M. 2011. Global water scarcity: monthly blue water footprint compared to blue water availability for the world's major river basins. Delft, The Netherlands: UNESCO-IHE.

15 Hoekstra, A. Y.; Chapagain, A.; Aldaya, M. and Mekonnen, M. 2011. The water footprint assessment manual. Setting the global standard. London, UK. Earthscan. 228 p.

16 Kluender, E. 2013. Quantification of water footprint: calculating the amount of water needed to produce steel. The Journal of Purdue Undergraduate Research. 3:50-57. 10.5703/jpur.03.1.08.

17 Kubitza, F. 2017. pH da agua regula excrecao e toxidez de amonia. Revista Panorama de Aquicultura. 27(160):14-23.

18 Le Roux, B.; Van der Laan, M.; Vahrmeijer, T.; Annandale, J. G. and Bristow, K. L. 2018. Water footprints of vegetable crop wastage along the supply chain in Gauteng, South Africa., Water . 10:539-545. https://doi.org/10.3390/w10050539.

19 Lennard, W. and Ward. J.2019. A comparison of plant growth rates between an NFT hydroponic system and an NFT Aquaponic System. Horticulturae. 5(2):27-34. https://doi.org/10.3390/horticulturae5020027.

20 Martínez, Y. R. 2013. La Acuaponía como alternativa de producción agropecuaria sostenible ¿Una posibilidad para tener en casa? REDICINAySA. 2(5):16-23.

21 Mekonnen, M. and Hoekstra, A. 2011. The green, blue and grey water footprint of crops and derived crop products Hydrol. Earth Syst. Sci. 15:1577-1600. 10.5194/hess-15-1577-2011.

22 Monsees, H.; Suhl, J.; Maurice, P.; Kloas, W.; Dannehl, D. and Würtz, S. 2019. Lettuce (*Lactuca sativa*, variety Salanova) production in decoupled aquaponic systems: Same yield and similar quality as in conventional hydroponic systems but drastically reduced greenhouse gas emissions by saving inorganic fertilizer. PLoS One. 14(6).

23 Oltra, M. y Melgarejo, J. 2020. Huella hídrica y sostenibilidad de los recursos hídricos en la provincia de Alicante. El agua en la provincia de alicante. Alicante, España. Diputación Provincial de Alicante Universidad de Alicante.

24 Orjuela, M. A. y Vargas, D. F. 2016. Estrategias para el uso eficiente del agua a partir de la estimación de huella hídrica en cultivos de lechuga (*Lactuca sativa*) y brócoli (*Brassica*) para una finca de diez hectáreas en mosquera cundinamarca. Tesis de Licenciatura. Universidad de La Salle, Colombia.

25 Pérez-Rincón, M.; Hurtado, I.; Restrepo, S.; Bonilla, S.; Calderón, H. and Ramírez, A. 2017. Water footprint measure method for tilapia, cachama and trout production: study cases to Valle del Cauca (Colombia). Ingeniería y competitividad. 19(2):115-126. https://doi.org/10.25100/iyc.v19i2.5298

https://doi.org/10.29312/remexca.v15i3.3304

26 Portillo, A.; Muñoz, C.; López, D.; Pinto, F.; Cristancho, H.; Gironza, M.; García, M.; Gil, R. y Echavarría, V. 2020. Catálogo de identidad 2019. Bogotá, Colombia: SWISSAID.

27 SADER. 2019. Secretaría de Agricultura y Desarrollo Rural. Conozcamos un poco más sobre la lechuga. Gobierno de México. México, DF.

28 SAGARHPA. 2018. Secretaría de Agricultura, Ganadería, Recursos Hidráulicos, Pesca y Acuicultura. En 2017 aumentaron las exportaciones agrícolas de Sonora 22%. Gobierno de México.

29 Sendanayake, S. 2016. Life cycle analysis of ferrocement rainwater tanks in Sri Lanka: a comparison with RCC and HDPE tanks. International Journal of Advances in Engineering Research. 12(2):30-42.

30 SIAP. 2019. Servicio de Información Agroalimentaria y Pesquera. Avance de Siembras y Cosechas. Resumen por estado. http://infosiap.siap.gob.mx:8080/agricola-siap-gobmx/ResumenProducto.do.

31 SIAP. 2020. Servicio de Información Agroalimentaria y Pesquera. Al alza, producción y exportación de lechuga mexicana. https://www.gob.mx/agricultura/prensa/al-alza-produccion-y-exportacion-de-lechuga-mexicana?idiom=es.

32 Shi, R.; Ukaew, S.; Archer, D.; Hee, J.; Pearlson, M.; Lewis, K. and Shonnard, D. 2017. Life cycle water footprint analysis for rapeseed derived jet fuel in north dakota. ACS Sustainable Chemestry and Engineering. 5(5):3845-3854.

33 Somerville, C.; Cohen, M.; Pantanella, E.; Stankus, A. y Lovatelli, A. 2022. Producción de alimentos en acuaponía en pequeña escala. Cultivo integral de peces y plantas. FAO. Documento técnico de pesca y acuicultura 589. FAO, Roma. 10.4060/i4021es.

34 Tolón, A.; Lastra, X. y Fernández, V. 2013. Huella hídrica y sostenibilidad del uso de los recursos hídricos. Aplicación al Poniente Almeriense. Revista Electrónic@ de Medio Ambiente. 14(1):56#86.

35 Valenzuela, R.; Martínez, P. y Arévalo, J. 2017. Evaluación preliminar de un sistema de recirculación de aguas para un prototipo implementado en la producción de tilapia roja (*Oreochromis* sp.). Ingeniería y Región. 18(2):25-33. https://doi.org/10.25054/ 22161325.1737.

36 Wang, F.; Wang, S.; Li, Z.; You, H.; Aviso, K. B.; Tan, R. R. and Jia, X. 2019. Water footprint sustainability assessment for the chemical sector at the regional level. Resources, Conservation and Recycling. 142:69-77. https://doi.org/10.1016/ j.resconrec.2018.11.009.

37 Water foodprint network. 2016. Global average water footprint.

38 Wilson, A. 2018. Los hidropónicos: guía suprema de los hidropónicos para salvar tiempo y dinero. Barcelona, España. BABELCUBE-Books.

39 Zaman, A. and Newman, P. 2021. Plastics: are they part of the zero-waste agenda or the toxic-waste agenda? Sustain Earth.4. https://doi.org/10.1186/s42055-021-00043-8.

40 Zárate, E.; Fernández, A. y Kiuper, D. 2017. Guía metodológica para la evaluación de la huella hídrica en una cuenca hidrográfica. Instituto Interamericano de Cooperación para la Agricultura (IICA). San José, Costa Rica.

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