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Utilising Reclaimed Water for Papaya (*Carica papaya* L.) Cultivation in Cape Verde: A Detailed Case Study

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Abstract: Papaya (*Carica papaya* L.) is essential for food security, providing economic benefits in tropical and subtropical regions. However, its high water requirements pose challenges, especially in water-scarce areas like Cape Verde. This study hypothesises that reclaimed water (RW) irrigation can promote papaya production and investigates how water can be managed to ensure sustainability and increase agricultural productivity. An experiment was conducted using *Carica papaya* L. var Solo-nº8, focusing on subsurface drip irrigation (SDI) with RW. Three irrigation treatments were compared, namely, T1: RW with SDI; T2: RW with drip irrigation (DI); and T3: conventional water (CW) with SDI. The study evaluated crop yields and water use efficiency (WUE) over 13 months, monitoring soil and water quality and papaya growth and yields. Despite quality concerns, RW maintained soil fertility and ensured sustainable reuse. Papaya demonstrated high adaptability and productivity under experimental conditions. T1 significantly increased the cumulative fruit yield (69 t/ha) compared to T2 (65 t/ha) and T3 (62.7 t/ha). T1 also had the highest WUE (5.97 kg/m^3), demonstrating the effectiveness of RW and SDI in optimising water use. The results indicate that RW can be a viable alternative to conventional water sources, providing new insights into sustainable agricultural practices and improving food security in arid and semi-arid regions.

Keywords: water management; yield; subsurface drip irrigation; sustainable food production; water use efficiency; recycled water

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1. Introduction

Papaya (*Carica papaya* L.) is a fruit crop often described as a fast-growing, semi-woody giant herb. Papaya production is an important agricultural activity worldwide, particularly in tropical and subtropical regions. This crop contributes to food and nutrition security as well as providing economic benefits to farmers. The papaya plant grows in tropical climates with low altitudes (less than 300 m.s.l), high irradiation and humidity, and rainfall more than 1200 mm per year. Papaya also has high thermal requirements, preferring areas with temperatures in the range of 21–33 °C [1]. It is a tropical fruit crop that produces large-sized berries of high nutritional value. Due to its enormous productivity, early bearing, and nutritional value [2] papaya is also very popular in many subtropical areas. This crop requires a considerable amount of water during its cycle, making proper irrigation management essential for optimal water use [3]. Burbano-Figueroa et al. [4] pointed out that smallholder farmers in the tropics face numerous threats that often undermine their capacity to obtain enough food and income. Papaya is a long-term crop (18 months) of high-risk and profit that can provide smallholders with an opportunity to invest in short-lived perennial crops. A recent study by Sharma et al. [5] mentioned a significant potential demand gap between area and production for papaya in the future. The aforementioned authors [6] point out that India is the largest producer of papaya, contributing 42% of the global production. However, the highest yield is achieved by Mexico, followed by Brazil, and the average global yield is 29.6 t/ha [7].

In Europe, especially in south-eastern Spain, papaya production under glass has been shown to be viable and profitable [8]. Varieties grown under these conditions meet the quality requirements of the European market [9,10], providing sweeter fruits for consumers. Since 2016, papaya production in the Canary Islands, another Macaronesian archipelago like Cape Verde, has increased from 10,000 tons to 24,000 tons, both for the domestic market and for export (from 10.2% in 2012 to 34.4% in 2022), generating export revenues of more than EUR 10 million in 2023, calculated this based on ISTAC data. [11]. Since the 1980s, successive Cape Verdean governments and various international cooperation projects have supported the introduction of productive and economically interesting species and varieties of fruit trees. Recent introductions include the Solo group of papaya trees ('Sunrise Solo', 'Improved Sunrise Solo', and 'Sunset'). In terms of fruit production, the estimated annual production in Cape Verde for 2021 was 7154 tons, consisting mainly of bananas (around 68.9% of total production), followed by papaya (15.2%) [12]. In 2020, the annual production of papaya in Cape Verde, together with other fruits, reached about 8600 tons. This data highlights the growing importance of fruit production in the country's agricultural economy [13].

Prolonged drought periods, exposure, erosion, and soil degradation have been identified as the main constraints to agrarian development in the archipelago. Even though severe land degradation has strongly affected both people's livelihood and the environment in Cape Verde [14], the irrigation and forest sectors are located in the very low erosion risk zone in this country [15]. Therefore, water scarcity and dependence on rain-fed agriculture are the main challenges that the agriculture sector in Cape Verde is facing [16]. The strategies of Cape Verde's government to mitigate water scarcity through small-scale irrigation based mainly on small dams and drip irrigation technology have a marked effect on agricultural production [13], as water use efficiency (WUE) and irrigation management techniques are critical to optimising production and crop sustainability in semi-arid regions [17]. In a global study of the effects of reclaimed water (RW) irrigation [18], the results indicated that RW irrigation is beneficial for improving crop yield, WUE, and irrigation WUE (IWUE), giving values of 16.8, 23.8, and 18.7%, respectively.

As pointed out by FAO [19], the adoption of sustainable irrigation practices is crucial to reduce the environmental footprint of agriculture and promote the efficient use of natural resources. In this sense, papaya production faces significant challenges related to the availability and quality of irrigation water and is strongly influenced by soil quality and management practices, as its production is negatively affected by the salinity of irrigation water, which increases the electrical conductivity of the soil [20] and also affects papaya physiological processes. These processes include internal CO_2 concentration, transpiration, water use efficiency, and carboxylation efficiency [21]. WUE is critical for papaya production in semi-arid regions, with productivity of 0.95 kg of papaya per m^3 of water used [3]. Soil management practices also contribute to more efficient irrigation. In this sense, the use of drip irrigation combined with straw mulch significantly improved the water use efficiency and yield of papaya, especially when 50% of the crop's water requirement was applied [22]. Non-conventional resources can help mitigate the hydrological imbalance between water consumption and the availability of renewable resources [23]. These resources would improve the sustainability of production and can be applied through subsurface drip irrigation (SDI), where the safe use lies in the management rather than the level of water treatment [24,25]. Farmers tend to spontaneously adapt new technologies or packages to their specific needs, resources, knowledge, and strategies in their own way, modifying, adjusting, and adapting the proposed technologies and farming systems. This is an additional challenge for researchers and agronomists trying to support change [26]. Reuse irrigation projects can avoid the competence of conventional water and reuse nutrients added by RW, allowing a reduction in food imports by improving food sovereignty and farmers' profitability, and would increase resilience to the effects of climate change [27]. SDI provides additional security, as the soil acts as an additional treatment [17], avoiding the risk of mismanagement of treated water. That is why, in addition to improving irrigation and fertiliser use efficiency, SDI has also been applied in research on the safe utilisation of unconventional water resources (wastewater and salt water) and the optimisation of soil conditions [28]. The European standard (mandatory for papaya exports to EU countries) allows the use of Class C reclaimed water, easily produced by small water treatment plants in rural communities, for irrigation by SDI, which avoids direct contact with the edible part of the crop [29]. In addition, a recent regulation in Cape Verde includes irrigation with reclaimed water [30] to promote the safety and sustainability of reuse.

This study aims to evaluate the impact of reclaimed water irrigation on papaya production, focusing on the choice of irrigation system and water management. To the best of our knowledge, this is the first study conducted in Cape Verde to analyse papaya production irrigated with treated water, which is now mainly discharged into the sea. It contributes to the development of sustainable irrigation practices that optimise the use of resources while maintaining high agricultural productivity and ensuring food safety. Our results provide insights into the feasibility and potential benefits of using reclaimed water in papaya production.

2. Materials and Methods

2.1. Experimental Field

In February 2021, an experiment with *Carica papaya* L. var Solo n° 8 was carried out in a field (360 m^2) in Rocha Lama (15°7′43″ N; 23°31′38″ W. 6 asl), Santa Cruz, Santiago Island, Cape Verde. This variety is characterised by a small fruit size (300–650 g), has a good flavour and aroma, and is well adapted to local conditions. It is well accepted by Cape Verdean farmers and consumers. The area has a warm, humid and sunny climate, with an average minimum temperature, maximum temperature, and humidity of 20.7 °C, 24.1 °C, and 71.6%, respectively, from 2007 to 2021 [31]. The total rainfall and ET recorded during the period studied (from February 2021 to March 2022) were 198 mm and 1682 mm [32].

Prior to this experiment, the field was cultivated for 3 years with the *Sorghum bicolor* Payenne variety. A more detailed description of the climate can be found in Palacios-Diaz et al. [31]. A mixture of water, vegetable oil, and neutral detergent was used for pest control in two applications (July and October 2021). Traps were also set to monitor and control *Ceratitis capitata* and *Bactrocera invadens*.

The experimental field was irrigated with three treatments based on water quality (conventional vs. RW) and drip system (subsurface drip, SDI vs. surface drip, SFDI): T1: RW applied by SDI; T2: RW plus SFDI; and T3: conventional water plus SDI, with an area of 60 m^2 for each plot [27]. These plots were replicated in two blocks where all three treatments were watered (six plots). The experimental unit (plot) consisted of eight lines transplanted in alternate rows, 0.75 m apart and 10 m long, with three plants per line, giving a total of twelve plants per plot, equivalent to 2000 plants per hectare. For each irrigation treatment, estimated CROPWAT [33] water use data were calculated, with irrigation times programmed from evapotranspiration (ET) data provided by the Santa Cruz automatic meteorological weather station [32] and soil water sensors. Although Caar [34] summarised that there are no reliable published values for Kc, in our study, cultivation coefficients (Kc) for papaya were obtained from Migliaccio et al. [35], resulting in a calculated total ETc of 2117 L/m^2. The same amount of water was applied to both SDI and SFDI, giving a total of 1035.5 L/m^2 provided by the irrigation system over the entire 13-month study period (equivalent to 956 L/m^2/year). As a result, only 58% of the ETc was available to the crops, since the rainfall was 198 L/m^2 in the studied period of 13 months. On 54 days, the irrigation system was stopped due to rainfall or infrastructure problems (power failure or pump malfunction).

2.2. Irrigation System

The experimental field had an irrigation head with a controller and two different pipelines, with each having a pump and a sand filtration system for each water quality. An ultraviolet light disinfection lamp was also used in the RW. Integral drippers were used at a flow rate of 2.3 litres per hour. Lateral lines were spaced 0.75 m apart and buried 0.20 m deep. Irrigation was applied twice a day. Each treatment had its own flow meter [31].

2.3. Water Quality

Water from the Sta Cruz WWTP was used for the T1 and T2 treatments. This WWTP is characterised by low energy consumption and is suitable for many rural villages in Cape Verde. The treatment system consists of a pre-treatment area, an anaerobic digester as a primary treatment, and a series of vertical flow gravel filter beds as secondary treatment. The total designed water treatment capacity was 1000 m^3 per day. Recently, this plant has effectively treated 200 m^3 per day [36]. The characteristics of the treated water, analysed by INLAB using an internal method based on the Portuguese Decree-Law 236 of 1998, are presented in Table 1. Groundwater from two wells (PT33 and FT 59) close to the experimental plot was used to irrigate T3 (Table 2). This groundwater was analysed by the Laboratorio Agroalimentario del Cabildo de Gran Canaria; pH and EC were analysed using electrometric methods (GLP21, GLP31 CRISON, HACH LANGE SPAIN, S.L.U.). Water samples were filtered through a 0.45-µm pore membrane filter. For the analysis metals and metalloids, a filtered aliquot sample was acid-stabilised (pH < 2) and stored at 4 °C until analysis by atomic emission spectroscopy optical emission (ICP-OES) (Optima 8000, PerkinElmer, Inc. Waltham, MA, USA). A second aliquot, for major anions (Cl^-, $NO_3{}^-$, and $SO_4{}^{2-}$), was stored frozen until ion chromatographic analysis (930 Compact IC Flex, Metrohm AG, Metrohm Hispania, Madrid, Spain). SAR was calculated using Equation (1):

$$SAR = ([Na])/\sqrt{((([Ca]^{+}\ [Mg])/2)}. \quad (1)$$

Table 1. Chemical parameters analysed in the treated water.

		pH	EC	COD	BOD_5	$NO_3{}^-$	SAR	Cl^-	Na	Ca	Mg	TSS
			µS/cm		mg/L		$(meq/L)^{1/2}$			mg/L		
RW	Mean	7.5	2970	32	6.3	320	6.8	415	361.6	91.3	71.4	2.2
	Std	0.7	355.9	1.4	0.4	157.2	2.2	35.4	91.3	5.5	9.9	0.2

Table 2. Chemical parameters analysed in the groundwater from two wells.

Well		pH	EC	SAR	Na	K	Ca	Mg	Cl^-	$NO_3{}^-$	$SO4^{2-}$	B	Cu	Fe	Zn	Mn
			µS/cm	$(meq/L)^{1/2}$						mg/L						
PT33	Mean	8.1	1150	2.21	99	9.15	55	62	140	45.5	39.5	0.135	<0.015	<0.015	0.016	<0.005
	Std	0	50	0.03	1	0.05	1	2	0	1.5	2.5	0.005	-	-	-	-
FT59	Mean	7.95	1250	1285	65.5	7.3	96	60.5	190	45	46	0.07	<0.015	<0.015	<0.010	<0.005
	Std	0.04	106.1	0.01	2.47	0.28	9.9	5.3	42.42	0.71	1.41	0	-	-	-	-

2.4. Soil Analysis

The soils of the experimental field have been modified by human activity and have lost their horizons. According to the soil taxonomy [37], the soils belong to the suborder of Arents: Torriarents isoperthermic. According to the FAO classification [38], they would belong to the group of anthrosols, with the qualifier "irragric" and, considering the salinity recorded during the last sampling, also with the qualifier "salic".

Soil samples were taken from the first 0.2 m before papaya planting (December 2020) and after the first harvest (November 2021). Samples were collected from all treatments (Table 3).

Table 3. Soil properties sampled during the experiment: before papaya planting (December 2020: Dec-20) and before first harvest (November 2021: Nov-21) for each treatment (1: RWSDI, recycled water plus subsurface drip; 2: RWDI, recycled water plus surface drip; 3: CWSDI, conventional water plus subsurface drip).

			dS/m	%	%		mg/kg		meq/100 g				mg/kg
	Treat	**pH**	**CE**	**OM**	**Ntot**	**C/N**	**Nitrate**	**Polsen**	**K**	**Ca**	**Mg**	**Na**	**B**
Dec-20	1	8.8	1.1	2.9	0.18	8.95	862.5	141.0	7.8	18.5	10.2	8.7	2.0
	2	8.7	0.7	3.4	0.2	9.7	574.0	168.0	7.0	20.3	11.4	5.8	1.4
	3	8.9	0.5	2.1	0.1	9.9	202.0	78.0	5.8	21.4	11.6	8.0	1.4
Nov-21	1	8.5	0.5	3.0	0.2	9.8	353.3	153.5	5.9	20.9	13.2	2.9	1.7
	2	8.6	0.5	3.0	0.3	10.2	343.5	195.3	7.1	20.7	11.9	3.9	1.9
	3	8.9	0.4	2.8	0.2	9.6	142.8	127.0	6.2	19.8	12.3	3.5	6.0

The organic carbon (OC, %) and nitrogen (N, %) were determined by dry combustion (TreuMac analyser, LECO CNS 2000, LECO Corporation, Michigan, USA). Soluble salts were estimated by electrical conductivity at EC1:5 (soil:water ratio; dS/m) (GLP31, CRISON, HACH LANGE SPAIN, S.L.U). The available nitrate level was determined by soil extraction, also at a 1:5 ratio, with 0.01 M calcium chloride and was analysed by ionic chromatography (930 Compact IC Flex, Metrohm AG, Metrohm Hispania, Madrid, Spain). The available soil P (mg/kg) was extracted by sodium bicarbonate extraction according to the Olsen method [39] and analysed by the UV method (Spectrophotometer UV-1800, Shimadzu, Shimadzu Corporation, Kioto, Japan). Exchangeable cations (K, Ca, Mg and Na, meq/100 g) were extracted with buffered 1 M ammonium acetate at pH 7. Microelement B (mg/kg) was extracted with hot water at pH 7, and both microelements (after extraction with DPTA) and exchangeable cations were analysed by ICP-OES (Optima 8000, PerkinElmer, Inc. Waltham, MA, USA). All parameters were determined in the Laboratorio Agroalimentario del Cabildo de Gran Canaria.

2.5. Papaya Production, WUE and Fruit Quality

Three (3) plants were selected in each of the six experimental plots. These plants were used as reference standards for monitoring growth and production development (flowering, fruit type, and yield recording). Ripe fruits were collected weekly from each plant and weighed to record the fruit number and weight per tree and to calculate production per tree for each of the 26 weeks of harvest. The accumulated yield and water use (kg/m^3) for each treatment were used to calculate the WUE. In two of the harvests (fifth and sixth), a total of seven fruits were randomly sampled, separating the female fruits from the hermaphrodites to assess their quality by determining the total soluble solids (TSS) obtained using a portable digital refractometer.

2.6. Statistical Analysis

To analyse the papaya yield, a multivariate analysis of variance was performed using the SPSS statistical package (version 27, Armonk, NY, USA: IBM Corp.) by applying the generalised linear model (GLM).

The papaya yield was analysed by a multivariate analysis of variance using the generalised linear model, including the harvest date, treatment (T1: RWSDI, T2: RWDI, and T3: CWSDI), and their interactions as independent variables. The fruit weight and number of fruits per tree per week, the average weight produced per tree per week, and also the cumulative yield and total number of fruits per tree were considered as dependent variables. F-tests were performed based on linearly independent pairwise comparisons between the estimated marginal means. Levene's test was used to analyse the data, and the separation of subsets was tested with Tukey's test at alpha = 0.1 and 0.05.

3. Results and Discussion

3.1. Water and Soil

Cape Verdean regulation establishes the maximum admissible values (VMAs) and the maximum recommended values (VMRs) for some parameters according to the risk of contact with irrigated crops [30]. It also controls the agronomic quality of irrigation water, regardless of origin. This follows the recommendations of Ayers and Westcot [40], who said their guidelines are too restrictive for specialised irrigation such as localised DI. Although some parameters showed severe restrictions of use (nitrate, chloride, and sodium) and exceeded the VMA, others, such as EC, had a low to moderate restriction considering Cape Verdean regulations (Table 1). It is possible to drip irrigate with RW without adding fertilisers. For CW (Table 2), nitrate, EC, and Na were all below the VMA but above the VMR [31].

As shown in Table 3, despite the aforementioned restrictions on the use of RW due to excess nitrates, papaya uptake caused a decrease in this parameter in the soil, while the total N in reserve increased in all treatments. Both P and OM remained at high fertility levels (higher in plots irrigated with RW) despite the absence of additional inputs, with C/N values showing the stability of fertility. Salinity and Na decreased in all treatments. Therefore, soil fertility was maintained after this project, which guarantees the sustainability of the proposed water reuse.

3.2. Fruit Weight and Number, Fruit Produced per Tree per Week, and Cumulative Fruit Production

At each harvest, there was no significant difference in fruit weight between the three treatments (0.328, 0.334, and 0.354 fruit weight, in kg/fruit, for T3, T1, and T2, respectively). However, fruit weight varied over time, as there were weeks with significantly heavier fruits (week 8, on 10 November 2021) than the other weeks with lighter fruits (week 1, on 21 September 2021, and week 19, on 27 January 2022). There was a significant difference in the number of fruits per tree per week between T1 and T3 (2.90 and 2.20, respectively). T2 did not have a different number of fruits compared to the other treatments, with 2.54 fruits per tree per week. Related to time, there were weeks with significantly more fruits than others, which were ranked from the most fruits collected per tree (5.83 at week 13, on 15 December 2021) to the least (0.56 on 21 September 2021).

Average tree production per week over the whole period did not differ significantly between treatments, ranging from 1.21 (T3) to 1.33 (T1) kg/tree per week. However, as with fruit weight, this varied over time, as there were weeks when trees were significantly more productive (highest in week 8: 3.10 kg/tree per week, on 10 November 2021). Conversely, there were 7 weeks with lower tree production: weeks 26 (18 March 2022), 22 (17 February 2022), 1 (21 September 2021), 10 (24 November 2021), 19 (27 January 2022), 20 (3 February 2022), and 23 (24 January 2022), ranging from 0.31 to 0.51 kg/tree per week.

In terms of cumulative fruit production over time, the cumulative yield and the number of fruits per tree showed significant differences at the 10% and 5% levels, respectively. T1 trees yielded significantly more than T2 and T3 trees. In fact, at the end of the study, tree production was 34.53 vs. 32.54 and 31.33 for T1, T2, and T3, respectively (Figure 1). This gives equivalent calculated yields of 69,060 kg/ha, 65,080 kg/ha, and 62,660 kg/ha, respectively. These values are similar to those reported in other studies (Table 4). Similarly, the number of fruits collected throughout the period was significantly higher in T1 (75.33) than T2 (66.00) and T3 (57.17) (Figure 1).

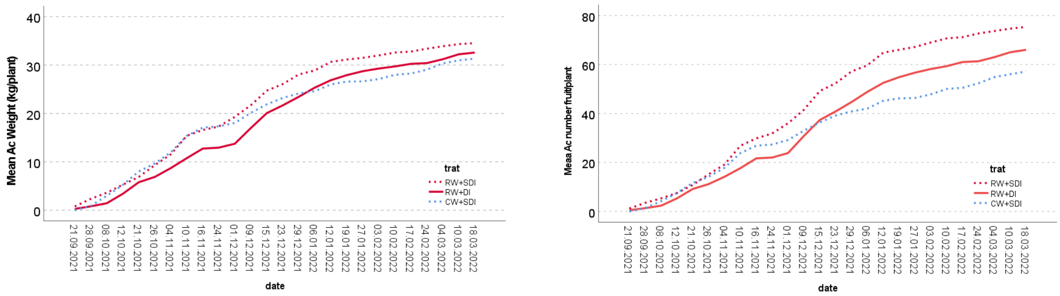

Figure 1. Cumulative fruit production and number of fruits over time for T1: RW applied by SDI; T2: RW plus SFDI; and T3: conventional water plus SDI.

Table 4. Fruit yield (kg/ha), water consumption (mm/year), and WUE (kg/m^3) in different regions reported by other authors.

Region	Fruit Yield (kg/ha)	Water Consumption (mm/year)		WUE (kg/m^3)	
Thailand	30,000–50,000	900–1100	I + R	4.55	[7] [41]
India	60,000–80,000	1200–1500	I + R	5.33	[7] [41]
India	50,000–70,000	1200–2000		3.5	[7]
Mexico (Veracruz)	113,200	1200–2000		5.66	[42]
Mexico (Colima)	80,100	1200–2000		4.01	[42]
Mexico (Oaxaca)	78,900	1200–2000		3.95	[42]
Mexico	50,000–70,000	1100–1300	I + R	5.38	[7]
Brazil	40,000–60,000	1000–1200	I + R	5	[7] [41]
Brazil	60,000–80,000	1800–2000		4	[7]
USA (Hawaii)	50,000–60,000	1200	R	5	[43]
Spain (southeast)	45,000–60,000	1200–2000		3	[44] [45]
Spain (Canary Islands)	40,000–50,000	700–900	I	5.56	[46]
Spain (Canary Islands)	50,000–70,000	1200–2000		3.5	[7]
Cape Verde	69,060	1256	I + R	5.97	This study (T1)
Cape Verde	65,080	1256	I + R	5.62	This study (T2)
Cape Verde	62,660	1256	I + R	5.42	This study (T3)

I: Irrigation
R: Rainfall

As shown in Table 4, based on data from experimental orchards, the highest yield was achieved in Veracruz, Mexico, which has a warm, humid, and sub-humid climate and a total annual rainfall of 1500 mm. In comparison with other studies of papaya grown with rainfall and irrigation in India, Mexico, and the Canary Islands, yields similar to those obtained in this study were reported with similar amounts of water, while slightly lower yields were obtained in Hawaii and southeastern Spain. In contrast, Thailand had the lowest yield, although it had lower water consumption.

Figure 2 shows the statistical yields of commercial orchards by country [7]. As can be seen, and in line with the data presented in Table 4, Mexico is the most productive country, with stable yields between 50 and 60 t/ha. Brazil has less stable yields, ranging from 50 to 40 t/ha, followed by India, with a yield of about 40 t/ha. The USA has the lowest yield, close to the world average (29.6 t/ha). In the same trend, Bayabil et al. [47] mention a yield of 32.49 t/ha produced in Florida. As can be seen, our yields of 57 to 75 t/ha are higher than those reported by commercial orchards, although they are in the way of scientific studies, as the papaya plants had proper water management provided by DI or SDI.

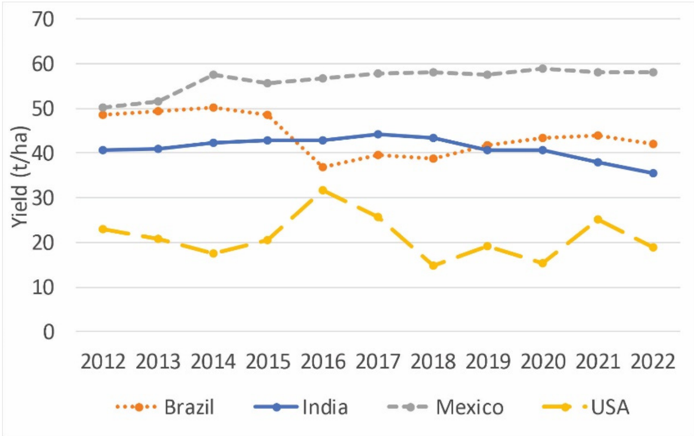

Figure 2. Yield (t/ha) of papaya production over time in selected countries. Source: Author's calculations based on FAO data.

In a study carried out in Brazil comparing micro-sprinkler vs. drip irrigation of papaya, Carvalho et al. [48] concluded that the best performance of the drip irrigation treatments can be explained by the moisture levels after irrigation at distances and depths that effectively focus the root system, in general, close to the field capacity over the surface and above the field capacity in the layers below 0.2 m deep, contributing to the supply of water and nutrients to the plants until subsequent irrigation. The authors achieved a papaya productivity of 51.26 to 51.44 t/ha with drip irrigation, which is lower than the 65 t/ha with DI and 69 t/ha with SDI using recycled water in our study, although they provided more relative water (calculated as rainfall plus irrigation/ET $\times$ 100) to the papaya plants (111.7% vs. 62.7%) than was used in our study. Therefore, reclaimed water, which can provide nutrients as the plant grows, offers a good opportunity for yield improvement. In another study carried out in a semi-arid region of Brazil [49], the authors obtained yields similar to those in our study when using similar amounts of water. They obtained a linear adjustment of yield with the amount of water, with a calculated maximum of 123.845 t ha^{-1} obtained for 3.349 mm.

3.3. Water Use Efficiency

The WUE values obtained for the different treatments in this study are shown in Table 4. The results obtained by the treated water showed better WUE (5.97 kg/m^3 and 5.62 kg/m^3) than conventional water (5.42 kg/m^3). The difference between the WUE values of the treated water-irrigated treatments is due to the irrigation system, with SDI being more water-efficient than DI (5.97 kg/m^3 vs. 5.42 kg/m^3), in line with previous results obtained on the same site when irrigating sorghum [31]. As expected, the differences in WUE obtained between treatments in papaya were smaller than those obtained in sorghum, where the whole plant is collected. Better WUE values than the other studies shown in Table 4 were achieved with the water management on this plot, which used recycled water through drip irrigation twice a day.

Manjunath et al. [50] studied the improvement of water use efficiency under limited water conditions by partial root zone-drying irrigation in papaya. The best WUE of 23.74 kg/m3 was obtained by shifting irrigation and 40% ER (evaporation replenishment), and the lowest of 7.11 kg/m^3 by shifting irrigation and 80% ER, with values ranging from 9.15 to 9.72 kg/m^3 for normal irrigation and 80% ER. However, a significantly higher number of fruits (54/plant) was obtained with normal irrigation, a value significantly lower than that obtained in our study (from 57 to 75). As the calculated ER for our study is about 63%, our WUEs of 5.4 to 6.0 are clearly lower than the values reported by the aforementioned authors, similar to those calculated using the data from the studies presented in Table 4, and higher than those reported by Carr [34], who reported water productivity values in the range of 1.8 to 2.8 kg of fresh fruit per m-^{3} of irrigation water applied.

Further studies conducted under water scarcity conditions by the aforementioned authors [51] recommend deficit irrigation of papaya at 1.5 m $\times$ 1.5 m spacing to maximise water use efficiency. Furthermore, the same authors [52] concluded that replenishing 60% of the evaporation resulted in a significantly higher number of fruits (46.1/plant), but fewer than were obtained in our study. In addition, when the irrigation sides were changed once every 12 days, significantly more papaya fruits (53/plant) and a higher total yield (32.4 kg/plant) were obtained, reducing water consumption by 14.3%, with a WUE of 10.0 kg/m^3. They concluded that this water management method was more economical with higher gross and net returns and a higher benefit–cost ratio (2.60). In our study, a similar yield per plant was achieved when using SDI-treated water, although the yield was lower due to the larger planting frame (2000 plant/ha instead of the 3086 plant/ha used by the authors). Therefore, with simpler water management, similar yields per tree can be achieved, although the reduction in the planting frame should be explored in order to obtain the economic results obtained by the aforementioned authors.

In a greenhouse experiment by Lima Santos et al. [53], who studied partial root zone drying in papaya, the highest average fruit yields were obtained in the full irrigation treatments (96,218 kg ha^{-1}). Using partial root drying (PRD), alternating lines every 14 days and reducing the irrigation depth by 35%, resulted in a better WUE (6.56), but with a yield loss of 12%. In our trial, possibly because it was carried out outdoors with a calculated ETc of 2117 mm and 58.27% of water supplied versus required, lower yields were obtained with a similar but slightly lower WUE, although the same WUE was obtained as that when the lines were alternated every 21 days.

The aforementioned study by De Melo et al. [49] obtained an inversely proportional linear relationship between WUE and the amount of water applied, the best value of which agrees with our WUE. They also obtained higher yields but with higher water application, resulting in lower WUE. Therefore, from the point of view of sustainability, especially in areas at risk of hydric emergencies, the recommended quantities of water must be those that provide greater profitability per unit of water applied, while ensuring an acceptable economic return for the farmer.

3.4. Fruit Quality: Total Soluble Solids

According to Dantas et al. [54], TSS is one of the main quality parameters of papaya fruits. The results of the analyses carried out showed that the TSS of the fruits evaluated was between 10 and 15°Bx, corresponding to values of 10 to 12°Bx in the hermaphrodite fruits and 12 to 15°Bx in the female fruits, which can be considered acceptable. According to Rodriguez and Lobo [55], the quality standard is a minimum of 11.5% soluble solids for marketing. The authors concluded that quality variation is strongly influenced by the environmental conditions, variety, harvest time, season, ripening stage, and cultural practices. Cabrera et al. [56] concluded that the phenology during the fruit development showed critical periods in which technical or management strategies can be applied to improve the quality of the fruit. Although given an equation with a poor correlation level, these authors concluded that, under their cultivation conditions, the ratio between the number of fruits per plant/leaf area and the period of fruit development was the main factor influencing papaya fruit TSS. Other studies concluded that water supply did not modify fruit TSS levels, which varied between 10 and 12 degrees Brix (°Bx) in fruit from well- or deficit-irrigated "Siluet" plants [57]. In addition, Manjunath et al. [58] also concluded that the TSS of papaya fruit was not significantly affected by either the dose or the source of fertigation.

4. Conclusions

Despite the risk associated with the quality of the reclaimed water mentioned in the Cape Verde regulations, soil fertility was maintained, ensuring the sustainability of the proposed water reuse. The fruit weight and fruit number varied significantly over time, making it difficult to find significant differences between treatments. Nevertheless, the subsurface drip irrigation with reclaimed water (T1) produced a significantly higher cumulative yield than the other treatments (T2 and T3), with calculated yields of 69 t/ha, 65 t/ha, and 62.7 t/ha, respectively, ensuring a good fruit quality. The yields in this study were higher than or comparable to those reported in other studies using similar amounts of water. Therefore, it is feasible to replace conventional water with treated water in papaya production using subsurface drip irrigation, which also ensures sanitary protection.

The difference between the WUE values of the treated and irrigated treatments is due to the irrigation system, with SDI being more water-efficient than DI (5.97 kg/m^3 vs. 5.42 kg/m^3), in line with previous results with other species. Since there is an inversely proportional linear relationship between WUE and the amount of water applied, from a sustainability point of view, especially in areas at risk of hydric emergencies, the recommended amounts of water must be those that provide greater profitability per unit of water applied, while ensuring an acceptable economic return for the farmer. The reduction in the planting frame should be studied to increase the yield and achieve better economic results. In conclusion, this study has shown that it is possible to replace groundwater with reclaimed water using subsurface drip irrigation, as it is safe and cost-effective. This substitution of groundwater with reclaimed water releases a good-quality natural resource for alternative use as drinking water. Food sovereignty is enhanced by making this resource available to farmers instead of discharging it into the sea.

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