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Desalinated and Brackish Water Conjunctive use in Irrigation Strengthening Adaptation and Resilience in Water-Scarce Regions Santiago Island - Cape Verde

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Summary

The scarcity of water resources remains a global challenge. Finding alternatives to increase water availability is an imperative for adaptation and resilience in Cabo Verde. The research developed consisted in evaluating the use of desalinated, blended[1] and brackish water in a light textured soil and its impacts on the productivity of tomato (*Solanum lycopersicum*), sweet potato (*Ipomoea batatas*) and zucchini (*Cucurbita pepo*) crops. The yield of tomato crop, irrigated with blended water (T2 with 2.5 dS/m), was 23.38 ton/ha; followed by irrigation with blended water (T3 with 3.5 dS/m) with a yield of 16.56 ton/ha, and irrigation with brackish water (T4 with 5.75 dS/m) whose yield was16.93 ton/ha. The lowest yield recorded (4.8 ton/ha) was with the treatment T1, irrigation with desalinated water. Regarding fruit quality, no significant variations were observed in tomato quality parameters, however, the variety Savana F1 is sensitive to apical rot. The average weight of the fruits differed according to the treatments: T1 (33.3g), T2 (39.7 g), T3 (32.4 g) and T4 (26.9 g). In terms of yield decrease (Q_y) the following values were recorded: T1 (Q_y =79.5%), T3 (Q_y =29.2%) and T4 (Q_y =27.6%) compared to the best treatment, T2 (23.38 ton/ha). The zucchini crop despite being moderately sensitive to salinity, did not adapt to the environmental conditions of the trial. The yield of sweet potato crop, irrigated with T1, was 14.6 ton/ha, followed by T2 with 11.08 ton/ha and T3 with 9.15 ton/ha. The lowest value verified (5.87 ton/ha) was with T4, brackish water. Regarding tubers quality, no significant variations were observed, but the average weight was better with the T1 treatment (199.4 g) followed by T2 (181.5g) and T3 (141.4g) and lastly T4 (126.3g). In terms of Q_y, T2 (Q_y =24.1%), T3 (Q_y =37.3%) and T4 (Q_y =60%) were the best compared to T1 (14.6 ton/ha).

The results show that irrigation with blended water (desalinated and brackish) in adequate doses is a solution for increasing water availability and strengthening the resilience of agricultural systems in Cabo Verde (SID).

Keywords: Desalinated; Blended; Brackish Water; Irrigation; Soil; Agriculture Productivity

Introduction

Desalination of brackish water to obtain potable water has been studied for many centuries by Mediterranean and Middle Eastern civilizations. However, applied research for the development of large- scale, commercial desalination technologies began in the United States of America in the early 1960s (Buros, 1999) and has traveled to various regions of the world. In this decade, progress was made in desalination and desalination plants evolved considerably. In the 1970s, some countries in the Persian Gulf, due to their high scarcity in fresh water and ready availability of energy, bet heavily on desalinated water. In the beginning, the desalination plant was used to improve water quality, but the development of membranes allowed reducing energy consumption [1] and consequently expanding its use to saltier waters and even seawater. Water is at the heart of sustainable development and concerns the central promise of Goal 6 of the 2030 Agenda, which advocates universal and equitable access to safe drinking water and sanitation. However, the deterioration of water quality has become increasingly frequent. According to the World Health Organization (WHO), the allowable limit of salinity or total dissolved solids (TDS) in fresh water is 500 ppm, and values of 1000 ppm can be accepted in water for agricultural irrigation purposes. Generally, most surface waters have a maximum TSD up to 10,000 ppm, much lower than sea water whose salinity ranges from 35,000 to 45,000 ppm [1,2].

However, in Cabo Verde, over-exploitation of groundwater has caused the salinization of freshwater, which is now the condition of many wells and boreholes in coastal areas. Hence, this resource is considered a more promising one for desalination than seawater, due to its huge volume availability and lower desalination costs. Technologies to desalinate brackish water are available and their efficiency has been enabling desalinated water to cover agricultural demand in various arid regions of the world. Therefore, among the options for increasing freshwater resources in Cabo Verde, there is desalination of brackish groundwater. Today, although there is extensive experience in using desalinated water for agriculture, desalination technologies are only used regularly in a few countries due to the high costs involved in the process. However, in the context of Cabo Verde, desalination is a necessity, given the frequent occurrences of severe and extreme droughts, which cause a lot of pressure and constant imbalances in the balance between demand and supply of water and especially its availability for agricultural practice. Thus, in 2021/2022, INIDA installed a pilot unit for desalination of brackish water for agriculture, aiming to evaluate the effectiveness and feasibility of using desalinated, blended and brackish water on soil and agricultural productivity.

Research goals

The overall objective of this research is to evaluate the use of desalinated, blended and brackish water in a light textured soil and its impacts on the productivity of tomato (*Solanum lycopersicum*), sweet potato (*Ipomoea batatas*) and zucchini (*Cucurbita pepo*) crops and the quality of fruits and tubers. The specific objectives of this research are to evaluate the effects of: Irrigation water quality and its impacts on soil; Irrigation water quality and its impacts on tomato, zucchini and sweet potato crops.

Research Hypothesis

To initiate this study the following research hypothesis was made: irrigation with desalinated, blended and brackish water in light textured (sandy loam) soils may have consequences on the productivity of tomato, sweet potato and zucchini crops and the quality of fruits and tubers. Such consequences can be mitigated by mixing desalinated water with brackish water in certain proportions.

Material and Method

Case Study Location

The case study is the Aguada watershed, located in the Municipality of Santa Cruz/Santiago Island, about 50 km from the City of Praia in Cabo Verde. The basin is configured between the large basins of Ribeira de Saltos to the North and Ribeira de Santa Cruz to the South, near the Figueira Gorda dam. The Ribeira de Aguada (Figure 1) has an area of 473.26 ha, a main watercourse of 5.3 km and a maximum altitude around 410 m.

Figure 1: Aguada, Santa Cruz, Santiago Island - Cabe Verde.

Climatic conditions

The closest climatological station to the evaluated agricultural area is Santa Cruz (Achada Colaço). The climatic records observed during the trial period are summarized in Table 1. The data were made available by the National Institute of Meteorology and Geophysics (INMG).

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Table 1: Climatological variables and their observed annual mean values (2020- 2021).

Maximum Temperature (°c)	Minimum Temperature (°c)	Total precipitation (mm)	Reference evapotranspiration, ET0 (mm)	Average relative humidity (%)	Average wind speed (m/s)	Average insolation (W/m2/day)
30,73	19,07	16,27	3,09	70,69	2,77	29,13

Achada Colaço Climate Station, 15°06'37.45" 23°31'14.59"- Santa Cruz.

Pilot experiment installed

Desalination unit installed

The methodology applied was based on the installation of a pilot unit, desalination plant, which uses the reverse osmosis technique powered by photovoltaic solar energy (Figure 2). The desalination plant has the capacity to treat between 21 to 40 m^3 of water per day, and can be expanded to 100 m^3 in a blended or hybrid system. The Aguada desalination plant has the capacity to produce 8 m^3/day. The kWh cost of solar energy is 40% less than that of the electric grid. For a production of 40 m^3/day the kWh cost is about 88% less than that charged by the power company. Cabo Verde has good levels of daily solar radiation, receiving more than 3,000 hours of sunshine per year, favorable conditions for the implementation of photovoltaic projects. For this investigation, a deep well (borehole) 30 m deep was drilled, with a flow rate of 8 m^3/h, with a submersible pump at 26 m, whose water electrical conductivity corresponds to 9.6 dS/m. The water from the deep well is pumped using solar energy in a solar field area of 126 m^2. The installed solar power unit has a total of 80 solar panels covering an area of 1.44 m^2 each.

Figure 2: Brackish water desalination units.

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Solar Energy

Experimental plot, crops and irrigation tested

The research was conducted over a 6-month period (August to February) of 2021/2022, outdoors, in a pilot unit in Aguada. The experiment was conducted in the farmer's field where the desalination unit was installed. Tomato, sweet potato and zucchini crops are commonly used by farmers, the first two being classified as moderately salinity sensitive and the third as moderately salinity tolerant (Maas 1986). Zucchini was sown directly, tomatoes were transplanted after 23 days of sowing in the nursery, and sweet potatoes were planted from cuttings or branches. In all three crops a base fertilization (granulated N P K) and a top dressing (soluble N P K and urea) were done according to the recommendations of the INIDA Horticulture Technical Sheet, 2000. Fertilization was done based on the chemical analysis of the soil. We also did the phytosanitary treatment according to the needs, being the fruit fly and the mites, the main pests found in zucchini and tomato respectively. There were also some diseases in tomatoes, including powdery mildew and Alternaria.

Tomato and sweet potato crops have a long growing and yielding period and allow clearer information regarding the effect of irrigation water with different salinity levels on both soil and plants.

The crops were watered with four treatment categories (T), as detailed below:

- T1: Desalinated water (100% fresh water) (ECw 0.541 dS/m)
- T2: Blended water I (ECw= 2.5 dS/m. 50% brackish water /50% desalinated water);
- T3: Blended water II (ECw= 3.5 dS/m. 75% brackish water / 25 desalinated water) and
- T4: Brackish - Well water in use by most farmers (Ecw= 5.75 dS/m)

The experimental plot of INIDA, was designed with the following dimensions: 17 meters wide and 30m long, totaling an area of 510m^2. The area was divided into 4 experimental sub-plots. Each sub-plot consisted of 6 rows 17m long, i.e., 3 double rows, two with tomato, two with sweet potato and two with zucchini, and these rows were spaced at 0.70m apart. The planting spacing was 0.4m in the rows and 0.7m between rows for tomato and sweet potato crops (Figure 2 & 3). For zucchini, the spacing was 06m in rows and 07m between rows (Figure 3). In each sub-plot the 3 double rows were considered as useful area. At the ends of each sub-plot, a buffer zone (2 x17m) was considered.

Figure 3: Soil preparation of the experimental field.

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The soil was prepared by tillage, using hand hoes, to plant the tomato and sweet potato crops, and zucchini by direct seeding. Subsequently, a total of 6 raised beds were built, equidistant and approximately 0.20m high, where the three crops were established (Figure 4).

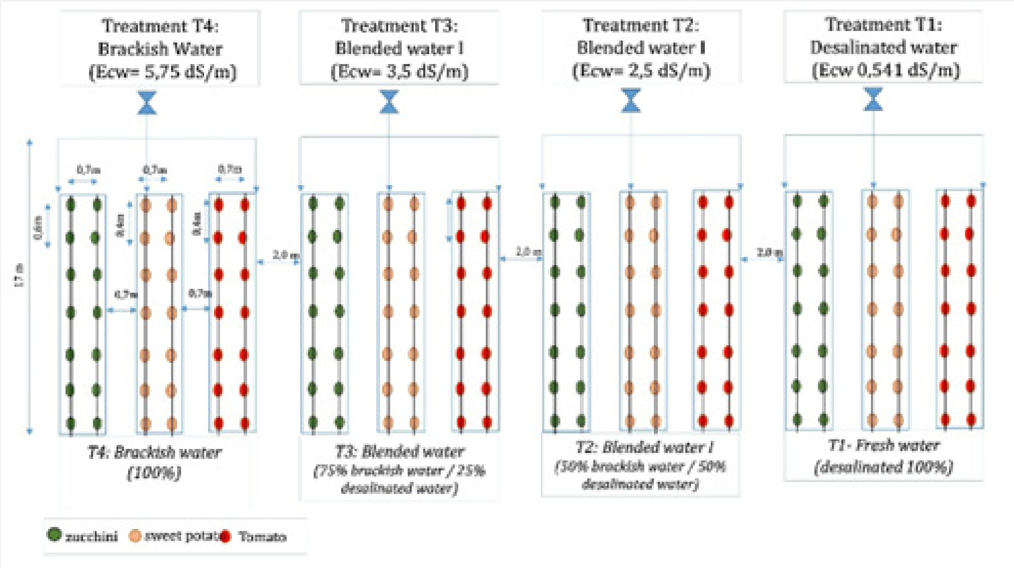

Figure 4: Experimental arcs, irrigated with desalinated, blended I, blended II, and brackish water.

Main Culture Parameters

In Cabo Verde few cultivated plants are halophytes, salt-tolerant plants. These plants, due to high rates of absorption and accumulation of salts in tissues, especially in the aerial part, have the ability to extract salts from the soil. However, most cultivated plants in the country are glycophytes, with a few exceptions such as the coconut and date palm. In this study, the records of crops sensitive and moderately tolerant to salinity were prepared, in which the varieties, duration and stages of the vegetative cycle were recorded. The suitability of irrigation water was taken into account in the preparation of the four treatments tested. Irrigation water in general is classified into four levels as shown in Table 2.

Table 2: Table of water salinity levels applicable in agricultural irrigation.

Level	Adequacy of water for irrigation	mS/cm	dS/m	µs/cm	ppm
Level I	Well suitable a fairly well suited for irrigation	1.3-0.1	1.3-0.1	1300-100	871-67
Level II	Reasonably well suited to poor for irrigation	2.2-1.4	2.2-1.4	2200-1400	1474-938
Level III	Very poorly suited for irrigation	3.2-2.3	3.2-2.3	3200-2300	2144-1541
Level IV	Extremely poorly suited for irrigation	5.0-3.3	5.0-3.3	5000-3300	3350-2211

Source: Adapted from http://bps.net.au/cms/wp-content/uploads/2015/04/EC-Conversion-Chart.pdf

The characterization of these crops in terms of vegetative cycle, fraction of water depletable without causing water stress (p), crop height (h), root depth (Zr) are presented in Table 1. Salinity tolerance and vegetative cycle length are summarized in Tables 3 & 4 [3]. To assess the impact of treatments on vegetative and reproductive growth of tomato, sweet potato, and zucchini crops, plants were evaluated until the end of the cycle (120, 75, and 120 days respectively). The crops were inspected weekly and evaluated during harvests. These, were selected from different plants within each of the 4 treatments, for the 3 crops. After harvests the fruits and tubers were evaluated for weight, caliber and quality. The yields of each of the crops were also evaluated.

Irrigation water analysis

The conductivity analyses of the water used for irrigation were determined in the INIDA laboratory, in order to obtain a tolerable conductivity, according to the conditions of the soil and crops in question. The salt concentration was determined taking into

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account the electrical conductivity of the water (ECw) in dS.m-1, at 25 °C. For each irrigation water treatment, with different TDS, chemical analysis was conducted, to study the parameters of chemical properties, as summarized in Table 5.

Table 3: Dates of the development periods for the crops, tomato, sweet potato, and zucchini.

Culture	Relative crop tolerance* to exchangeable sodium (Ayers; Westcot, 1999)	Development Period	Date	Cycle Duration in days	Total Cycle
Tomato Var. Savanna F1	Moderately Sensitive - MS SL $^{3-}$ (dS m-1) =2.5 b. % per dS m-1= 9.0	INI - Phase I - Planting	12/08/2021 12/09/2021	31	The harvest occurred about 60 after trans-planting and the cycle lasted about 120 days
		CRES- Phase II	13/09/2021 17/10/2021	34	
		INT - Phase III	18/10/2021 19/11/2021	32	
		1st harvest	(18/10/2021)		
		2nd Harvest	(02/11/2021)		
		3rd harvest	(12/11/2021)		
		FIN- Phase IV	19/11/2021 13/12/2021	34	
		3rd harvest	(22/11/2021)		
		4th Harvest	(09/12/2021)		
Sweet potato Var. Irene	Moderately Sensitive - MS SL $^{3-}$ (dS m-1) =2.80 b. % per dS m-1= 14.0	INI - Phase I - Planting	12/08/2021 02/09/2021	21	The harvest occurred at 118 days after planting. The lasts about 120 days.
		CRES- Phase II	03/09/2021 09/10/2021	36	
		INT - Phase III	10/10/2021 09/12/2021	60	
		FIN- Phase IV (Harvest (12/10/2021)	10/12/2021 --- .---	1	
Zucchini F1 Nadita +	Moderately tolerant - MT SL $^{3-}$ (dS m-1) =4.70 b. % per dS m-1=33.0	INI - Phase I Planting	12/08/2021 01/09/2021	15	Direct seeding Harvest starts 45- 80 days after planting 75
		CRES- Phase II	02/09/2021 12/11/2021	21	
		INT - Phase III	13/11/2021 22/12/2021	30	
		FIN- Phase IV Without Siginificant harvest given its sensitivity to pests (fruit fly)	23/12/2021 22/01/2022	9	

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Table 4: Dates of development periods and values of cultural parameters: Kc, p, h and Zr for the crops, tomato, sweet potato and zucchini.

Culture	kc	p	h(m)	Zr (m)
Tomato Var. Savanna F1	0.6	0.4	0.10-0.25	0.15-0.25
	0.6-1.18	0.4	0.25-0.45	0.25-0.50
	1.18	0.4	0.45	0.5
	1.18-0.80	0.4	0.45	0.5
Sweet potato Var. Irene	0.6	0.65	0.10-0.15	0.10-0.25
	0.60-1.10	0.65	0.15-0.30	0.25-0.40
	1.1	0.65	0.3	0.4
	1.10-0.50	0.65	0.3	0.4
Zucchini F1 Nadita +	0.4-0.45	0.4	0.10-0.15	0.10-0.15
	0.65-0.75	0.4	0.15-0.30	0.15-0.20
	0.9-1.0	0.4	0.30-0.35	0.20-0.25
	0.7-0.8	0.4	0.34-0.40	0.25-0.30

Note: The characterization of these crops in terms of crop coefficient (Kc), fraction of water depletable without causing water stress (p), crop height (h), root depth (Zr).

Table 5: chemical properties, of irrigation water, of different TDS.

Chemical Parameter	Un.	T1 Desalinated water	T2 Blended Water I	T3 Blended Water II	T4 Brackish Water (Well 52-106)
pH	--	7,3	7,3	7,4	7,48
ECw	dS\m	0,54	2,5	3,5	5,75
TDS	(g/L)	0,35	1,8	2,6	4,2

Physical-chemical parameters of soils

Soil density (bulk density) is defined as the ratio between the mass of a soil sample dried at 105°C and the sum of the volumes occupied by the particles and by the pores, given by the following formula:

$$\rho = \frac{\overline{Ms}}{V} \text{ (kg/m}^3\text{) or g/cm}^3$$

ρ - density that includes the pore space of the soil

The volumetric ring method was used. A kopeck ring, with sharp edges and an internal capacity of 100 cm^3 was used. These rings were nailed on the wall of the profiles and on the soil surface, to collect the samples. The ring was transferred to an appropriate container, still in the field, in order to avoid the loss of material. And in the INIDA Laboratory the soil samples were dried in an oven at 105º and after weighing, the soil density was then calculated, using the following formula:

$$Ds = M / V$$

Ds is the soil density;

M is the mass of the sample;

V is the volume of the sample

In general, it can be stated that the higher the density of the soil, the greater its compaction and degraded structure, the lower its total porosity, and consequently the greater the restrictions for root system growth and plant development. Determining the bulk density of a soil profile allows us to evaluate certain properties, such as: drainage; porosity; hydraulic conductivity; air and water permeability; saturation capacity; and water storage and available water. Low-density soils are recommended for tuber-producing crops (for example, sweet potatoes). Density restricting root development is not the same for all soils. Soil density can also interfere with seed germination (e.g. zucchini). It can interfere with the concentration of proteins and sugars in fruits (e.g. tomatoes).

Bulk density values

The density of soils is expressed in grams per cubic centimeter or kilograms per cubic meter and the ranges are within the following limits (Table 6):

The soils studied in the experimental area have the values of bulk density in the range of 1.25 to 1.60 g/cm^3, giving indications that these soils are light-textured soils, typical of alluvial soils of volcanic and mountainous regions. The parameters of the evaluated soils, undisturbed samples, are summarized in Table 7.

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Table 6: The ranges of variation of bulk density.

Types of Soil Texture	Values of density apparent soil
Clay soils	from 0.90 to 1.25 g/cm3
sandy soils	of 1.25 to 1.60 g/cm3
humid soils	from 0.75 to 1.00 g/cm3
Peaty soils	and 0.20 to 0.50 g/cm3

Table 7: Parameters of the soils evaluated in the experimental plot of INIDA.

No. of undisturbed samples	Volume of soil cm^3	dS=apparent density or natural density (g/cm^3)
1	100	1,256
2	100	1,229
3	100	1,131
4	100	1,114
5	100	1,303
6	100	1,198
7	100	1,259
8	100	1,072
9	100	1,235
10	100	1,255
11	100	1,596

Soil moisture content

The value of volumetric soil moisture in %, i.e. the volume of water contained in a given volume of soil sample, is the same moisture that is obtained in the evaluation with undisturbed samples taken with rings of known volume ($100cm^3$). In this study the water content was determined on a volume basis, i.e. the volumetric soil moisture in %. In the case study it was found that the volume of water contained in the volume soils of the different samples evaluated is very small (0.01 to $0.133cm^3/cm^3$).

Soil Analysis: conductivity, temperature and pH

To study the impact of irrigating with water with different salinity levels, soil samples were collected in the row and between the rows of each treatment before and after the field experiment was conducted. The electrical conductivity in the saturated soil stratum was measured for each treatment (T1, T2, T3, T4, at 25 ºC).

The evaluation of soil electrical conductivity was performed in the INIDA Laboratory, using samples collected from soil at five depths: 0.0-5.0 cm; 0.5-10.0 cm; 10.0-15.0 cm; 15.0-20.0 cm; 20.0-25.0 cm, and 25-30.0 cm, in both rows and between rows. ECs and pH analyses were done respectively by the conductivity bridge method and the electronic pH meter method. In the month of August, before the tests, a rainfall of 78.2 mm occurred, which corresponds to 40 m^3. This precipitation allowed a washing of salts in the soil. After the rainfall, in the row, the recorded ECs was 1.97 dS/m. and in the between row, the ECs was 0.54 dS/m. Most crop fields are considered good for cultivation if the conductivity does not exceed 4 dS/m (mS/cm). However, this number varies with the type of crop and its ability to tolerate salinity, as well as the type of water applied in irrigation.

The soils of the experimental plot are in condition to be cultivated, although there is an accumulation of salts in the superficial areas (0-15 cm) and in the deeper layers (20 to 30 cm). The soil conditions of the experimental plot before the trials are shown in Table 8. For the plot was previously irrigated with brackish water by the farmer. However, the condition of the soils would be much worse if it were not for the leaching that occurred after the August rains.

Air, water, and soil temperatures also affect the electrical conductivity readings. Soil conductivity involves the measurement of ions in the sample. These ions become extremely active when the temperature gets warmer. A higher activity means that the ions are better able to carry an electric current. Thus, the conductivity of the soil increases. As the temperature cools down, the ions calm down and move less. Less activity means that the ions have less power to carry an electric current. This decreases the conductivity of the soil. In the case study it was found that the pH of the soil tends toward alkaline and this can influence the electrical conductivity results. The more acidic or basic the pH, the more ions there are. The more ions, the higher the electrical conductivity. Therefore, the more acidic or basic your soil is, the higher the conductivity will be. The closer to neutral (pH 7.00), the less it will affect the conductivity of the soil.

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The texture of the soil influences the amount of moisture available. This affects the conductivity of the soil. The moisture helps release the ions so they can be read more accurately. Sandy soils do not hold moisture for long, so it may exhibit a lower conductivity. Clay-rich soils have a higher conductivity because they have a good ability to hold moisture, and soils with a medium conductivity tend to have the highest crop yield. All these parameters were taken into consideration in the analysis and evaluation of the electrical conductivity of the soils under study, since they directly interfere with the productivity of the soils and the crops under study. Water with very low salinity (ECw less than 0.6 dS/m) can cause waterlogging in light textured soils. Water with high salinity can be applicable in irrigation if it is mixed with other water with much lower salinity, which is called "conjunctive or conjugate use". Irrigation with desalinated water alone can impoverish soils in terms of availability of essential minerals. Desalinated water, if not managed intelligently can have unexpected consequences, both in terms of low productivity of some crops and in terms of scarcity of salts and consequently of other essential nutrients (Ca, Mg and S), which are usually removed during reverse osmosis. These minerals must be introduced into the desalinated water in adequate amounts before it is used for irrigation. Otherwise, yields may be at or near zero. The introduction of these nutrients will incur an additional cost to the desalination water production process, if it is by way of purchasing fertilizers, to make the water suitable for irrigation. The easiest and most correct route is to mix desalinated water with brackish groundwater, which was one of the options carried out by INIDA during this research, using blended water (T2 and T3).

Result and Discussion

Effects of salts on the plant and crop tolerance to salinity

The successful use of brackish or saline water for irrigation of agricultural crops requires very appropriate management, starting from the selection of salinity-tolerant crops, to the adoption of appropriate irrigation schedules and allocations, in order to avoid salinization of the soil. A good soil and water management is fundamental because it allows keeping the salt concentrations in the root zone as low as possible, corresponding to the tolerance capacity of the crops. Thus, for each treatment the salt concentrations in the soil at different depths were analyzed. The average salinity values in the row (2.2795 dS/m) and in the inter-row (0.4872 dS/m) were considered in the salinity evaluation in the soils before and after treatments according to Table 9.

Table 8: Soil conductivity, temperature and pH before and after soil washes (78 mm rainfall).

Experimental plot Sample collection points Conductivity dS/m		Before field experiment conducted		
		Temperature °C	pH	
In the line	0,0-5,0	3.0 99	25.7	7.27
	0,5-10,0	3.699	25.7	7.56
	10,0-15,0	1.971	25.7	7.47
	15,0-20,0	357	25.8	7.55
	20,0-25,0	2.548	25.8	7.7
	25-30,0	2.003	25.5	7.69
between the lines	0,0-5,0	447	25	7.7
	0,5-10,0	435	25.6	7.8
	10,0-15,0	543	25.6	7.7
	15,0-20,0	515	25.6	7.82
	20,0-25,0	496	25.6	7.78
	25-30,0	487	25.7	7.65

Table 9: The average salinity values in the row and between the rows of the experimental plot.

Treatment	Local	Ec(ds/m) - Before	Ec(ds/m) - After
T1: Soil irrigated with desalinated water	In the Row	2.28	0.25
	In Between the Rows	0.49	0.6
T2: Soil irrigated with blended water I	In the Row	2.28	0.51
	In Between the Rows	0.49	0.57
T3: Soil irrigated with blended water II	In the Row	2.28	0.55
	In Between the Rows	0.49	0.7
T4: Soil irrigated with Brackish Water	In the Row	2.28	0.85
	In Between the Rows	0.49	1.43

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Irrigation water quality with different salt contents and its impacts on soil

Treatment T1: irrigation with desalinated water with ECw 0.541 dS/m, when applied to the soil, in the row, with initial average ECs of 2.28 dS/m, caused a reduction of ECs to 0.25 dS/m in the row. However, between the rows there was a slight increase in salinity, from 0.49 to 0.60 dS/m (Figure 5a).

Treatment T2: irrigation with blended water I (ECw= 2.5 dS/m. 50% brackish water /50% desalinated water), when applied to the soil there is a decrease in ECs in the row from 2.28 to 0.51, and in the inter- row a slight increase from 0.49 to 0.57 dS/m (Figure 5b).

Treatment T3: irrigation with blended water II (ECw= 3.5 dS/m. 75% brackish water / 25 desalinated water) the same behavior was observed in the row and between the rows as in treatments T1 and T2. However in T3 the increase of salinity in the inter-row is more expressive, going from 0.49 to 0.70 dS/m (Figure 5c).

Treatment T4: irrigation with 100% brackish water - Well water in use by most farmers (ECw= 5.75 dS/m), when applied to irrigation, there is a slight decrease in salinity in the row from 2.28 to 0.85 dS/m and an increase in salt concentration in the inter-row from 0.49 to 1.43 dS/m (Figure 5d).

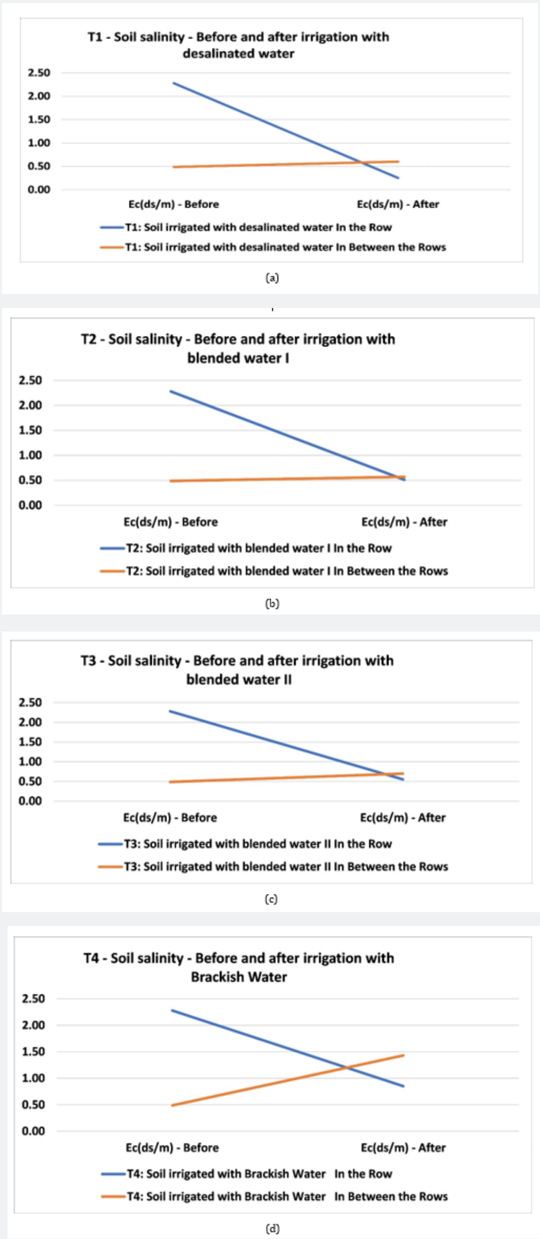

Figure 5: Brackish water desalination units.

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Of the four treatments, T1 contributed the least to soil salinity, while T4 contributed the most to soil salinity.

It was found that before the trials, salinity was higher in the rows than between the rows, for all subplots. After the treatments the salt levels decreased considerably in the rows (2.28 to 0.25 dS/m minimum at T1) and increased in the inter-rows (from 0.49 to 1.43 dS/m maximum at T4). The inter-rows generally have much less water, but are more subject to direct evaporation, which raises the concentration of salts at the surface. In the rows salts are generally leached to deep areas. In the inter-rows salts tend to accumulate on the surface, especially when irrigation is not done in the most efficient way, with water losses and waste. The proximity of the sea and the effect of the sea air can increase salinity between the rows, aggravated by cultural practices, high evaporation rates, and temperatures, typical of arid and coastal areas. Many factors can affect the electrical conductivity of soil. The most common are temperature, soil type, moisture level, salinity, irrigation, fertilizers, pH, texture, and the depth of the soil.

Irrigation water quality with different salt contents and its impacts on tomato, zucchini and sweet potato crops

The tolerance level of a plant species can be expressed in terms of the percentage of biomass produced or the percentage of survival. Expressing tolerance as a percentage of biomass produced under saline conditions, versus production under controlled conditions for an extended period, highlights disastrous differences among species. In this study we paid more attention to the level of survival and the productivity of the plant, fruits, and tubers. The trials showed differences between the three crops. Differences were found when comparing yields, average weights of the fruits and tubers harvested, and fruit quality under the different test conditions or treatments.

Results of irrigation with desalinated, blended and brackish water on zucchini yield

The yield of the zucchini (Figure 6) crop was practically zero. It is a crop essentially sensitive to arid and semi-arid zones, with high sensitivity to salinity, both in the soil and in irrigation water. In all treatments there was a very high leaf area index at the beginning. We advise against the use of this crop in hot seasons and in arid and semiarid zones. Although the zucchini crop is moderately sensitive to salinity, it is very sensitive to high temperatures. Abortion of flowers was recorded, aggravated by the salt stress situation.

Figure 6: Zucchini crop.

Results of irrigation with desalinated, blended and brackish water on Tomato yield

The yield of tomato crop irrigated with waters with different salinity levels allowed the following findings:

The tomato crop, when irrigated with desalinated water, T1, with ECw of 0.541dS/m

allowed a yield of only 4.8 ton/ha.

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- When irrigated with blended T2 water with ECw of 2.5 dS/m allowed a yield of 23.38 ton/ha;
- When irrigated with blended water T3 with ECw 3.5 dS/m generated a yield of 16.56 ton/ha;
- And finally when irrigated with brackish water T4 with ECw of 5.75 dS/m allowed to obtain a yield of 16.93 ton/ha

In relation to fruit quality, no significant variations in tomato quality parameters were observed. However, the variety Savana F1, used in this study, is sensitive to apical rot, and this sensitivity was observed in all treatments. What did vary was the average fruit weight, T1 (33.3g), T2 (39.7g), T3 (32.4g) and T4 (26.9g), Figure 7.

Figure 7: Tomato crop harvest.

In terms of yield drop, Qy, the highest loss was seen in the treatment T1 (Q=79.5%), followed by T3 (Q=29.2%) and T4 (Q=27.6%). The lowest loss was seen in the treatment, T2 (Q=14%). The research results on yield are in line with yields documented by MOA (PCBS 2007-2010) and according to Ibtisam Abu, 2015. The results indicated that watering light soils with desalinated water of different salinity has detrimental effects on tomato plant yields. In our case study, the negative aspects of irrigating tomatoes with desalinated water, T1, were mitigated by irrigating with blended water, T2 and T3, with relatively positive effects on both soil quality, plant productivity and fruit quality.

Brackish water, T4, allowed a yield similar to T3, but is not a solution that should be recommended because of the negative effects on the soil and the environment in general. As the salinity of the irrigation water increases, it will probably affect the relationship between soil, water and plants. The effect of water salinity on tomatoes has been studied by several researchers, especially tomatoes watered with brackish water with different ECw, namely (3000, 4000 and 5000 ppm). There are other experiments in which tomato was watered with different levels of saline water concentration (from ECw 4.5 dS/m to ECw 0.55 dS/m). The results indicated that increasing the water salinity level significantly reduced and has negative effects on tomato growth parameters such as plant height, leaf area, fresh and dry plant weight, flower number, fruit number, fruit size and weight, and plant productivity [4,5]; (Malasha et al., 2008; Kahlaoui et al., 2011; Al-Omran et al., 2010; Boamahet al., 2011) (Figure 8).

Under the influence of salt stress, the growth of many plant species is reduced, notably in sweet potato, bell pepper, banana, corn, cassava, tomato, onion and carrot [3] Significant differences in salt tolerance exist between plant species and genotypes and similar for the ability to tolerate water deficiency [6] (Lukovic et al., 2009). The main cause of reduced plant growth in the presence of salt may be reduced water regime. Increasing the salt concentration in the soil increases the osmotic pressure of the soil solution and plants cannot absorb water as easily as in the case of relatively non-saline soils.

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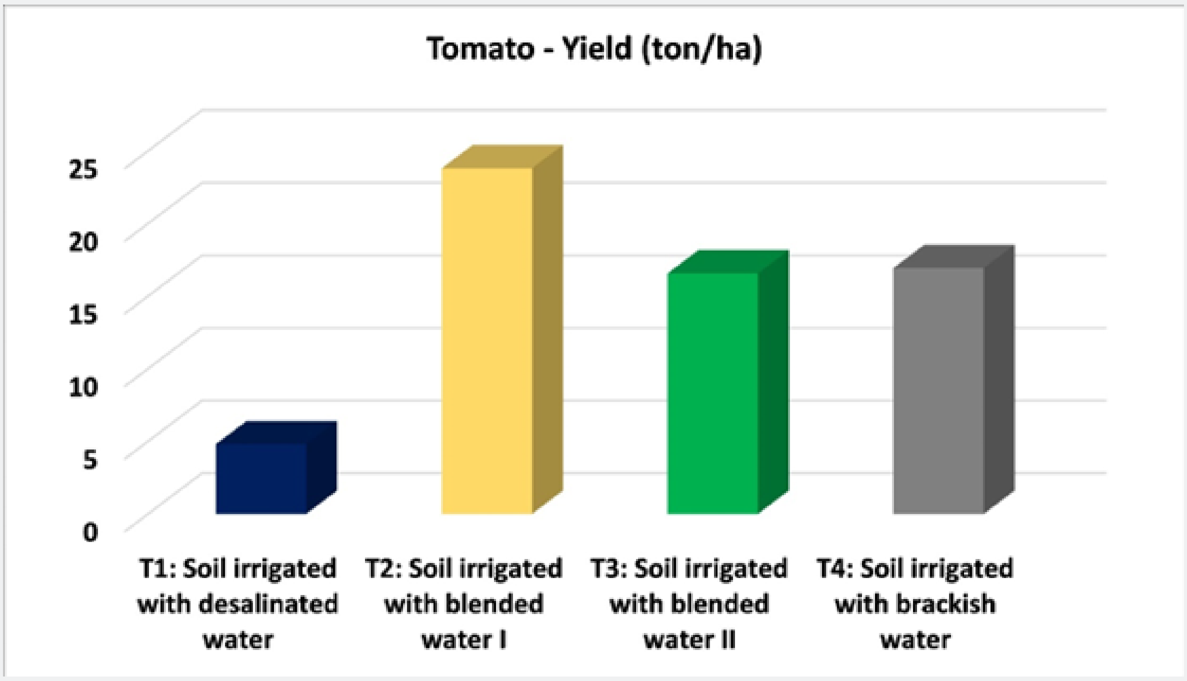

Figure 8: Tomato crop yield in the 4 treatments.

Therefore, as the salt concentration, that is, the ECs of the soil increases, water becomes less accessible to plants, even if the soil contains significant amounts of water and appears wet. Studies by Patil et al. [7], to test the response of bell pepper plant (cv. Taranto) to irrigation water quality, tested under two main water salinity treatments: non-saline water (EC=0.6 dS/m) and saline water (EC=3.8 dS/m), with peppers, irrigated with saline water led to a drop in fresh fruit yield from 1450.5 (non-saline water) to 1038.8 g/plant (saline water). The bell bell pepper (Capsicum annum) is a vegetable from the Solanaceae family, the same family as the potato, eggplant, and tomato. Probably this family is sensitive to desalinated water. Some researchers shared different results that showed that watering with desalinated water up to TDS 200 ppm can also have detrimental effects on crop productivity [8]. They reported that irrigation with fully desalinated water (200 ppm) maintained productivity less than 90% compared to irrigation with blended water up to 640 ppm. In our case, Cabo Verde-Aguada, from the study it was found that watering with desalinated water, lower than 350 ppm (0.541 dS/m) can also have negative effects on tomato yield. The best results were obtained with blended water with conductivity between 1800-2600 ppm. Results of irrigation with desalinated, blended and brackish water on the yield of Sweet Potato.

The yield of sweet potato crop irrigated with waters with different salinity levels allowed the following findings

The sweet potato crop, when irrigated with desalinated water, T1, with E C W d and 0.541 dS/m allowed a maximum yield of 14,8 ton/ha.

- When irrigated with blended T2 water with ECw of 2.5 dS/m allowed a yield of 11.08 ton/ha;
- When irrigated with blended water T3 with ECw 3.5 dS/m generated a yield of 9.15 ton/ha;
- And finally when irrigated with brackish water T4 with ECw of 5.75 dS/m allowed to obtain a minimum yield of 5.87 ton/ha (Figure 9).

Regarding tuber quality, no significant variations were observed in the parameters similar to tomato. However, the average weight was better in T1 (199.4g), followed by T2 (181.5g), T3 (141.4g) and T4 (126.3g). In terms of yield drop in T2 (Qy=24.1%), followed by T3 (Qy=37.3%) and T4 where the yield drop was 60%, relative to the best treatment, T1 (14.8 ton/ha) - Figure 10.

The sweet potato variety, Irene, is widely used in Cabo Verde, with good adaptation to arid and semi-arid conditions, despite its sensitivity to salinity. Treatment T1, irrigation with desalinated water, proved to be the best option for the crop under these soil and climatic conditions. It was also found that irrigating light soils with brackish or salinized water has detrimental effects on sweet potato plant productivity and tuber quality. The negative aspects of irrigating with saline water can be minimized by irrigating with blended water, T2, or at most T3. T4 treatment should be avoided as soon as possible. The survey results on production are in line with the production quantities documented by Moreno Â, et al. [9].

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According to them, the average yield and profitability for sweet potato in arid and semi-arid areas of Cabo Verde, under the same conditions, in terms of water and nutrient availability, ranges from 9 to 25 ton/ha per plant (Table 10).

Figure 9: Sweet potato crop harvest.

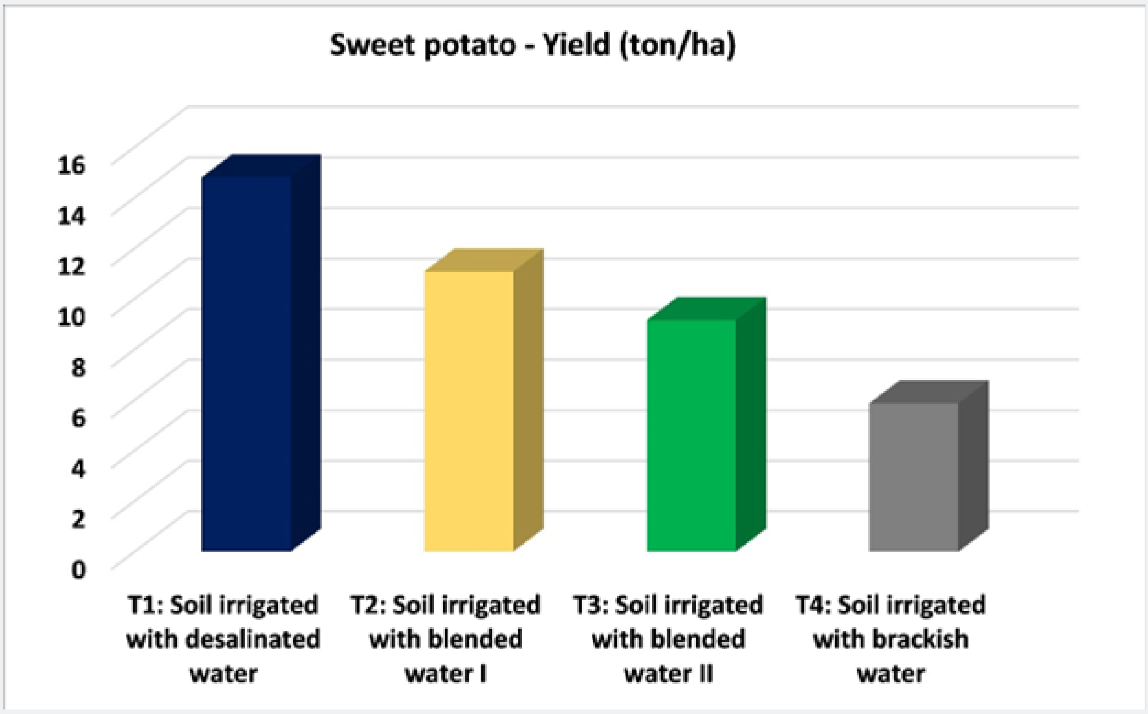

Figure 10: Yield of sweet potato crop for the 4 treatments.

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Table 10: Tomato crop yields in the main municipalities of Santiago Island.

Culture	Arid Zones	Irrigation Type	Ton/ha	Municipalities (Arid and Semi-arid Zones)
Tomato	Found farm	drop	22,58	Santa Cruz
Tomato	Old Town	drop	24,70	Ribeira Grande Santiago
Tomato	Achada Baleia	drop	15,73	Santo Domingo
Tomato	Variant	drop	9,44	Santo Domingo
Tomato	Tarrafal	drop	21,90	Tarrafal

Source: INIDA, A.Furtado and Â.Moreno 2022 [9].

Conclusion and Recommendation

The use of brackish water in semi-arid to arid Small Island Developing States (SIDS) is a matter of adaptation and resilience. Irrigation with desalinated, blended, brackish water can be an alternative. This study gave indications that these waters, when combined can increase the availability of quality water, improve yield and agricultural productivity. Reducing the salinity of the electrical conductivity of brackish water, T4 (ECw 5.75) to T3 (ECw 3.5 dS/m) and T2 (ECw 2.5 dS/m,) by reverse osmosis desalination, increased tomato crop yield to more than 3 times in T3 (4.8 to 16.56 ton/ha) and to more than 5 times in T2 (4.8 to 23.38 ton/ha). The studies give hints that moderately sensitive (MS) and moderately salinity tolerant (MT) crops can be grown using blended water. Mixing 50% saline water with 50% desalinated water raised the levels of salts and other essential minerals satisfactorily, while producing water with a salinity of ECw = 3.25 dS/m. Likewise, economic and environmental benefits of reducing irrigation water salinity from ECw 5.75 to ECw 2.5 dS/m in blended water T2 proved consistent in both tomato and sweet potato, blended option II, i.e., T2 treatment. Comparison of yields for sweet potato showed that irrigation with blended water maintained yields 62 and 75% for treatments T3 and T2 respectively, compared to irrigation with fully desalinated water (T1=14, 8 ton/ha) [10-12].

However, the economic and environmental costs of using desalinated water in production may not be the most attractive in the short to medium term. Desalinated water can be used to alleviate the salinization of soils by washing them or to increase the availability of water for irrigation by mixing it with brackish water. The precipitation that occurred during the trials contributed to leaching salts to deeper areas. The negative effects of using desalinated water on tomato production can be mitigated by irrigating with blended water (T2 and T3). In this research, the results show that irrigating salinized, light textured soils with desalinated water (T1) has detrimental effects on tomato plant productivity, quality and average weight of its fruit. The treatment (T1) proved to be the most effective on sweet potato crops and their tubers. The use of pure brackish water, treatment (T4), is not recommended for most horticultural crops, because besides the negative impact on irrigated soils, it endangers their salinity and consequently their fertility. Based on the results of this research it is concluded that several issues still need to be investigated, namely: (i) the effect of desalinated water and water movement in light and heavy textured soils along the soil profile; (ii) the amount of fertilizer needed under different levels of water and soil salinity; (iii) air, water and soil temperature and their effect on soil electrical conductivity; (iv) the influence of pH on results and electrical conductivity, soil texture its influence on the amount of available moisture; (v) cultural practices and water management, namely losses and waste of water in irrigation among others. Salinity is only one component of water quality assessment [13,14].

There are other components such as residual alkalinity ratio and absorption sodium that affect the quality of water for irrigation; the productivity of some crops, the scarcity of salts and consequently other essential nutrients such as Ca, Mg and S, which are usually removed during reverse osmosis desalination. Desalination of water for agriculture is technically feasible and the appropriate technology is available. Therefore, only economic and environmental considerations may limit its application. The main issues for discussion are: what size desalination plants; what are the best designs; the crops and areas where desalinated water could be applied; project financing, system maintenance, and form of management. Environmental issues also have to be evaluated and controlled. The successful use of brackish or saline water, for the irrigation of agricultural crops requires very appropriate management, starting from the selection of salinity-tolerant crops, to the adoption of appropriate irrigation schedules and allocations, in order to avoid salinization of the soil. In an ideal scenario, where conditions are favorable for the Aguada desalination plant to operate at full capacity, the investment costs to make such a venture viable would obviously be higher than those installed in this pilot system. For the price of desalinated water applied in irrigation to compete with current prices, there should be a policy of subsidies and mechanisms should be created for a stronger focus on more profitable crops from the economic point of view. In an ideal scenario, where conditions are favorable for the Aguada desalination plant to operate at full capacity, the investment costs to make such a venture viable would obviously be higher than those installed in this pilot system. For the price of desalinated water applied in irrigation to compete with current prices, there should be a policy of subsidies and mechanisms should be created for a stronger focus on more profitable crops from the economic point of view [15,16].

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