Potential Agricultural Use of Reject Brine from Desalination Plants in Family Farming Areas

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Abstract After drought, salinity is the second most important hindrance to sustain agriculture in the semiarid. Subterranean waters extracted from wells are often high in salts and, during dry years, this dependency on saline ground water precludes water and food security for small farmers and their families. Water desalination offers a potential solution to this problem, but the process results in a reject brine

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that needs to be properly disposed of to prevent increasing soil salinity and environmental degradation. This chapter considers desalination of naturally saline well waters as a potential solution to water and food security when used in conjunction with an integrated production system involving reject brine for farm-raised fish and the use of fish pond water to grow organic salt-tolerant vegetables and forage crops for small ruminants. We present results on the recovery of desalination systems in different small communities in the Brazilian northeast and chemical analyses of the saline water input, of the desalinized water, of the resulting reject brine, and of soils that received the desalinized water. Our results indicate that the use of desalination reject brine in family agricultural production is technically, economically, and socio-environmentally feasible, especially when using integrated and sustainable production systems.

Keywords Water desalination · Water security · Reverse osmosis · Fish farming · Family farming

1 Introduction

Throughout the rural areas of the Brazilian semiarid region, the great challenge is to ensure that families have access to good-quality water both for domestic and agricultural use (Souza et al. 2015). One of the economically feasible solutions is the use of groundwater, although, in most cases, its higher salt level restricts its use for human consumption and irrigation (Hach 2002; Knapp and Baerenklau 2006; Panagopoulos et al. 2019).

Reverse osmosis desalination has been the most commonly used method to purify brackish groundwater, and in this context, the Brazilian government program known as "Água doce" (fresh water) sponsored approximately 2000 reverse osmosis desalination plants in local communities and rural land settlements of the Brazilian semiarid region. The use of this technology has benefited 2.5 million people, alleviating the scarcity of freshwater supplies, a chronic condition that afflicts the Brazilian semiarid (Soares et al. 2006).

The desalination of water has been practiced since ancient times but has not been widely adopted due to technological limitations, high capital costs, high energy consumption, and finally, very high unit cost when compared to conventional municipal water (Tsiourtis 2001). Advances in technology in recent years have greatly reduced capital and energy costs, so that desalination projects can be considered as a way for acquiring good-quality water (Zotalis et al. 2014). However, besides potable water, desalination produces a hypersaline effluent (hereafter, referred to as reject brine) that can salinize soils if not properly discarded. In coastal regions, the reject brine can be disposed into the sea, but in remote inland rural locations, this is not possible due to the distance from the sea. In Brazil, studies have shown that reject brine is improperly discharged into soil and water bodies, causing major environmental impacts such as soil erosion, salinization, and contamination of water bodies

(Antas et al. 2019; Oliveira et al. 2018; Mohamed et al. 2005). Thus, the major challenge of using reverse osmosis lies in the disposal or reuse of the reject brine while avoiding environmental damage (Oliveira et al. 2017).

Converting the reject brine from a waste to a resource through treatment and beneficial use may minimize both costs and environmental impacts (Cath et al. 2013). There are reports of successful experiments demonstrating the use of reject brine in productive activities such as shrimp production, tilapia hatchery farming, vegetable and fodder production, laundry, and vehicle washing (Neves et al. 2017). The possibility of reuse is of great importance, considering that the number of desalination plants installed in northeastern Brazil has generated a large volume of reject brine.

In Brazil, some recent studies have pointed out that the reject brine has a potential for various agricultural uses (Dias et al. 2010). However, it is noteworthy that when used for these purposes, it requires the adoption of appropriate management strategies, because it is a highly saline water source, and its misuse can lead to great damage to the environment, such as soil salinization and desertification.

2 Water Desalination in the Brazilian Semiarid Region: Benefits and Impacts

2.1 Water Security in Isolated Communities

Groundwater is a water security alternative for isolated communities in the Brazilian semiarid region through deep well drilling under public policies. However, due to the high salinity of groundwater commonly observed, reverse osmosis desalination is an effective treatment widely used to reduce water salinity. In the Brazilian semiarid region, approximately 2500 desalination plants have already been installed, directly benefiting over 100,000 people in 212 municipalities. Each desalinizing unit produces approximately 10,000 L of desalinized water per week, enough to meet the needs of approximately 30 families. However, the efficiency of this system is variable, and several factors must be considered in a desalination project, such as system resilience, which result from the preliminary system design (Monteiro et al. 2009).

Reject brine volume is a function of the desalination plant size and water recovery rate, expressed as the percentage of the volume of freshwater produced to the total volume of saline water input (Panagopoulos et al. 2019). This rate is dependent on several factors such as membrane surface scale formation, osmotic pressure, and the quality of the water input. The higher the recovery rate of a system, the larger the volume of freshwater, and the smaller the volume of reject brine produced. The average water recovery rate is estimated to be around 45% and 80% for seawater and brackish reverse osmosis plants, respectively (Panagopoulos et al. 2019). Antas et al. (2019) evaluated the recovery rate of reverse osmosis from the desalination system in seven rural communities in the state of Rio Grande do Norte, Brazil, during 2013

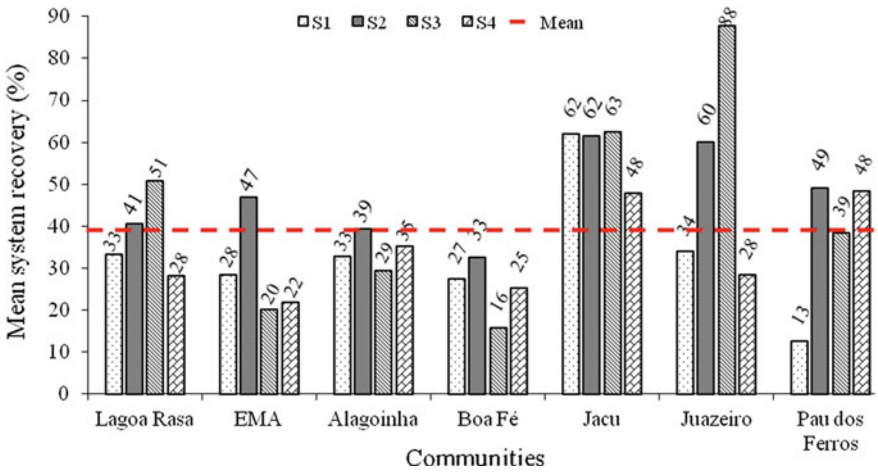

Fig. 1 Average water recovery rates of reverse osmosis desalination systems in seven rural communities of the state of Rio Grande do Norte, Brazil, during dry and rainy seasons in 2013 and 2014. The dotted red line shows the total overall mean across seasons. *Source* Antas et al. (2019). S1 = Season 1 (October/November-2013); S2 = Season 2 (February/March-2014); S3 = Season 3 (June/July-2014) and; S4 = Season 4 (October/November-2014)

and 2014. The authors found that in these, the values ranged from 13 to 88%, with an average of 39.3% (Fig. 1).

Another important aspect to be considered is the salt rejection of the membranes, that is, the ability of membranes to reject dissolved salts during water permeation, which indicates the effectiveness in removing salts and other chemical species (Antas et al. 2019). In general, the salt rejection rate ranges from 90 to 88.8% for most ions dissolved in the water (Hydranautics 2002). However, this ability is influenced by a wide variety of factors such as solute dimensions, retained component morphology, membrane pore size, chemical properties of the solution to be filtered, and hydrodynamic factors, which determine the drag stress and shear forces on the membrane surface (Schneider and Tsutiya 2001).

Antas et al. (2019) showed that 71% of the analyzed samples were within the acceptable range for salt rejection, that is, they had values above 90%, estimated by the electrical conductivity of the desalinated water (Table 1). This fact indicates that the salt rejection system in 29% of desalination plants did not have the required minimum efficiency. Problems of this type are usually related to lack of equipment maintenance. Yet, overall, reverse osmosis is a very efficient technology.

The chemical analysis of saline groundwater feed, reject brine, and drinking water (desalinized water) from the Santa Elza rural settlement is shown below (Table 2). Almost all salts were removed by desalination in the process of transforming feed water into fresh (potable) water.

Table 1 Salt rejection rate (%) in desalination plants from rural communities of the state of Rio Grande do Norte, Brazil

Locality	EC[a]	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	CO_3^{2-}	HCO_3^-
	Rejection rate							
Lagoa Rasa	98.99	100.00	97.22	98.57	97.93	82.35	100.00	97.62
Ema	95.37	100.00	96.46	98.15	94.29	96.05	100.00	95.89
Alagoinha	84.40	89.47	74.91	95.00	77.78	87.10	100.00	86.00
Boa Fe	94.68	81.82	94.19	98.78	94.95	96.89	100.00	90.91
Jacu	88.58	93.10	91.76	98.25	66.90	95.69	100.00	91.89
Juazeiro	93.03	95.00	93.59	99.00	97.99	95.88	–	80.00
Pau dos Ferros	92.38	91.67	92.20	98.06	100.00	94.34	100.00	96.88

Source Antas et al. (2019)
[a]Electrical conductivity

2.2 *Environmental Impacts of Reject Brine from Desalination Plants*

Despite the limited public understanding of the environmental benefits and challenges of desalination, this technology can be a valuable regional development tool for the Brazilian semiarid region. However, it is necessary to consider the environmental risks associated to the brine effluent co-produced during the desalination due to higher saline concentration than the feed water of the system. Hence, brine reject disposal, when carried out improperly, has great potential for negative impacts on the environment, including salinization of soil and contamination of water bodies (Moura et al. 2016). Reject brine, in addition to its high salinity, may contain dangerous pretreatment chemicals, organic compounds, and heavy metal (Panagopoulos et al. 2019).

Some studies have been performed to analyze the environmental impacts caused by the improper disposal of brine from reverse osmosis water plants. Anders (2013) evaluated these impacts in ten locations in Mossoró, Brazil (rural communities and settlements), and found that, at the point of discharge, 84.6% of soil samples collected were saline or sodic (Fig. 2a), while at 0.8 m and 1.6 m away from the discharge point, 81% and 66.7% of soil samples were saline, respectively (Fig. 2b, c). The authors concluded that there are risks of desertification; however, due to the large variability of soil analysis between the sites studied, it is suggested that desertification risk assessment should be made individually.

Studies at two brackish water treatment plants in western Rio Grande do Norte, Brazil, were conducted by Oliveira et al. (2018) to evaluate the potential agricultural use of reject brine and to identify problems concerning the salinization of soils that receive reject brine generated in the desalination plants. Samples of reject brine and soils in the area where this waste is disposed of were collected for physicochemical characterization. The results indicated that both samples of reject brine have highly

Table 2 Chemical analysis of feed saline groundwater, reject brine, and freshwater from Santa Elza rural settlement, Mossoró, Brazil

Water source	pH	EC	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	CO_3^{2-}	HCO_3^-	PO_4^-	SAR	Hardness	Cations	Anions
		$dS\ m^{-1}$	$mmol_c\ L^{-1}$							$mg\ L^{-1}$		$mg\ L^{-1}$	$mmol_c\ L^{-1}$	
Feed water	8.9	2.04	11.6	10.2	7.70	12.60	4.50	0.0	3.4	0.03	1.8	630	17.4	9.0
Reject brine	8.0	2.23	5.1	18.3	8.50	15.20	4.70	0.2	5.8	0.05	2.9	760	23.3	15.4
Freshwater	7.6	0.08	1.3	1.1	0.25	0.36	0.03	0.0	0.0	0.004	0.3	18	0.8	0.6

EC = Electrical conductivity, SAR = Sodium adsorption ratio

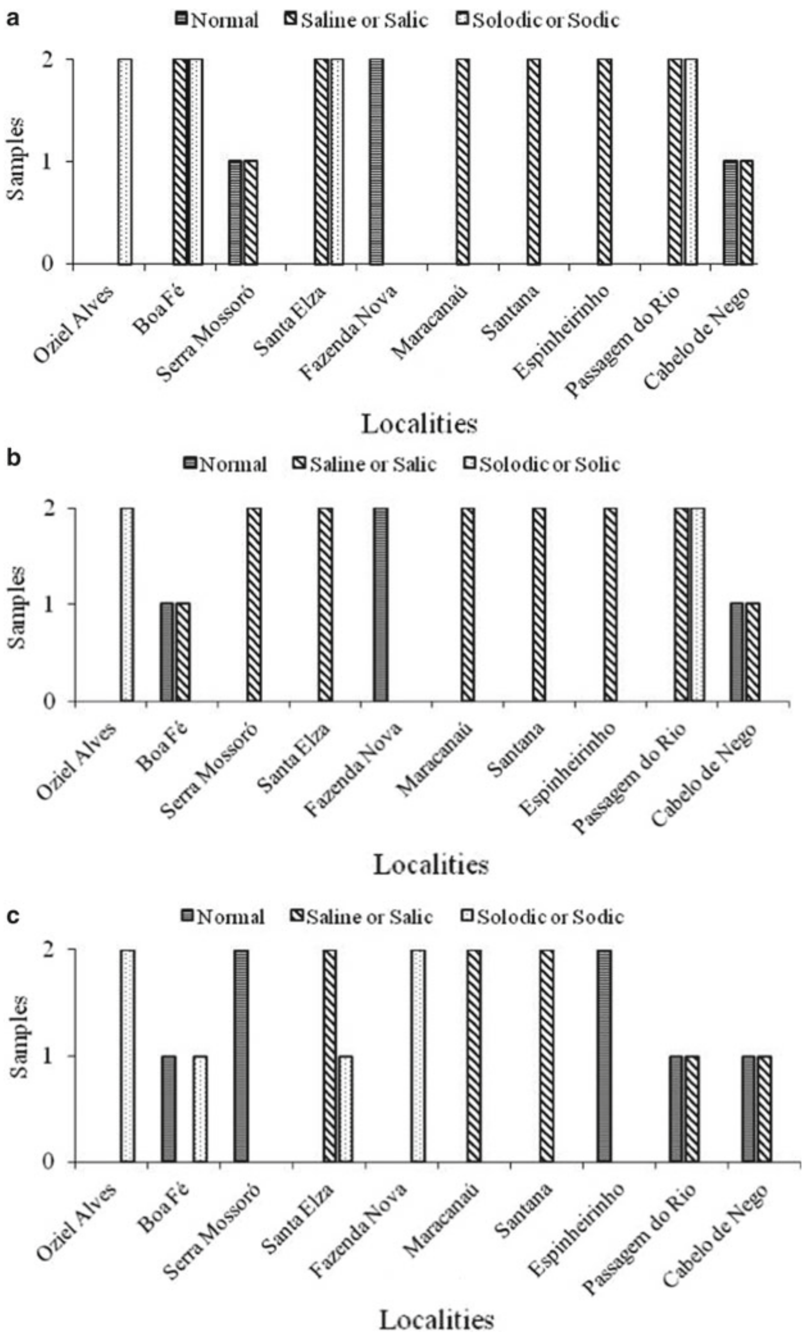

Fig. 2 Classification of soil samples for salinity and sodium saturation at the brine discharge point (**a**), at 0.8 m (**b**) and at 1.6 m (**c**) from the discharge point of reject brine in ten communities in the state of Rio Grande do Norte, Brazil. *Source* Anders (2013)

Table 3 Chemical analysis of the water from the reject brine from the communities Boa Fé and Lagoa Rasa in four periods of sampling

Locality	Seasonal climatic conditions	pH	EC	Na^+	Cl^-	*SAR	USSL[1]	S[2]	T[3]
			dS m^{-1}	$mmol_c$ L^{-1}					
Lagoa Rasa	Dry season 2013	7.63	1.48	10.24	5.00	6.00	C3	S1	T3
	Beginning of rainy season 2014	8.00	1.80	13.01	7.40	6.90	C3	S1	T3
	End of rainy season 2014	7.70	1.15	8.93	6.20	5.20	C3	S1	T2
	Dry season 2014	7.60	1.31	19.25	6.00	10.93	C3	S2	T3
Boa Fé	Dry season 2013	7.49	8.41	33.70	92.00	6.50	C4	S1	T3
	Beginning of rainy season 2014	7.02	9.30	38.90	100.0	7.10	C4	S1	T3
	End of rainy season 2014	7.20	7.30	40.09	87.00	7.12	C4	S1	T3
	Dry season 2014	7.35	7.56	72.63	82.00	12.11	C4	S1	T3

*Sodium Adsorption Ratio. SAR = $Na^+/(Ca^{++} + Mg^{++})^{0.5}$
[1,2,3]Classification of waters for irrigation with respect to potential risks of salinity (C), problems of infiltration—sodicity (S), and toxicity by ions (T), respectively (Ayers and Westcot 1999). *Source* of Data from table Oliveira et al. (2018)

restricted use for irrigation, being classified as C_3 or C_4 (Ayers and Westcot 1999) (Table 3). Due to the risks of salinization by the reject brine and the consequent deleterious effects of salts on soil and plants, these can be used in the irrigation of agricultural crops provided that a set of soil-water-plant system management strategies are established, such as the use of tolerant species, subsurface irrigation, and application of leaching fractions.

Due to the low SAR values, there is no restriction for the use of the reject brine in both communities regarding the risks of reduction in water infiltration in the soil. SAR values indicate that this water offers low to moderate risk of infiltration problems. However, the samples have moderate (Lagoa Rasa) to severe (Boa Fé) restrictions of use regarding toxicity, especially the samples from Boa Fé due to the high concentrations of Cl^- and Na^+ ions and the electrical conductivity, which is unsuitable for most agricultural and horticultural crops (Table 3).

Regarding soil salinization in the reject brine disposal area (Table 4), it was found that both localities had saline or saline-sodic soils (0.12–6.75 dS m^{-1}), with greater accumulation of salts in the dry period. The high values of exchangeable sodium percentage (ESP) determined indicate the predominance of sodium adsorbed in the

Table 4 Characteristics of soils that receive reject brine from the desalination plants from two localities in different seasons of the year. Data are from discharge point distances (0, 1, and 2 m) and from two soil depths (0–20 and 20–40 cm)

Season	Discharge point (m)	Layer depth (m)	Locality							
			Boa Fé (Mossoró[2])				Lagoa Rasa (Apodi[2])			
			pH	EC_e ($dS\ m^{-1}$)	ESP (%)	Soil classification[1]	pH	EC_e ($dS\ m^{-1}$)	ESP (%)	Soil classification[1]
Dry 2013	0	0–0.20	7.04	3.75	6	Saline	8.54	7.10	49	Saline-Sodic
	0	0.20–0.40	7.19	3.45	13	Saline	8.50	2.56	19	Saline-Sodic
	1	0–0.20	5.33	3.62	7	Saline	8.90	13.90	70	Saline-Sodic
	1	0.20–0.40	5.14	4.04	8	Saline	8.60	13.20	56	Saline-Sodic
	2	0–0.20	4.50	0.13	0	Normal	8.53	5.86	33	Saline-Sodic
	2	0.20–0.40	4.39	0.12	0	Normal	8.51	6.25	39	Saline-Sodic
Beginning of rainy season 2014	0	0–0.20	7.60	6.25	12	Saline	8.60	2.57	26	Saline-Sodic
	0	0.20–0.40	7.76	5.71	18	Saline-Sodic	8.70	2.70	28	Saline-Sodic
	1	0–0.20	7.84	5.25	16	Saline-Sodic	9.00	11.56	61	Saline-Sodic
	1	0.20–0.40	7.85	5.71	15	Saline-Sodic	8.88	8.95	49	Saline-Sodic
	2	0–0.20	8.15	5.37	13	Saline	8.93	7.65	46	Saline-Sodic
	2	0.20–0.40	8.25	5.00	17	Saline-Sodic	8.70	7.77	39	Saline-Sodic
End of rainy season 2014	0	0–0.20	7.53	6.75	13	Saline	8.83	3.51	18	Saline-Sodic
	0	0.20–0.40	7.50	7.02	21	Saline-Sodic	8.72	3.61	25	Saline-Sodic
	1	0–0.20	7.70	3.62	10	Saline	8.86	5.93	34	Saline-Sodic
	1	0.20–0.40	7.75	3.57	14	Saline	8.67	7.15	32	Saline-Sodic
	2	0–0.20	6.21	0.63	1	Normal	9.11	7.42	49	Saline-Sodic
	2	0.20–0.40	6.17	0.71	2	Normal	8.65	7.08	37	Saline-Sodic

(continued)

Table 4 (continued)

Season	Discharge point (m)	Layer depth (m)	Locality							
			Boa Fé (Mossoró[2])				Lagoa Rasa (Apodi[2])			
			pH	EC_e (dS m^{-1})	ESP (%)	Soil classification[1]	pH	EC_e (dS m^{-1})	ESP (%)	Soil classification[1]
Dry in 2014	0	0–0.20	7.43	4.25	10	Saline	9.11	2.81	20	Saline-Sodic
	0	0.20–0.40	7.62	4.16	11	Saline	9.17	3.47	28	Saline-Sodic
	1	0–0.20	7.73	3.50	11	Saline	9.49	3.43	32	Saline-Sodic
	1	0.20–0.40	8.31	4.16	17	Saline-Sodic	9.00	3.81	31	Saline-Sodic
	2	0–0.20	8.05	5.87	16	Saline-Sodic	9.53	4.53	49	Saline-Sodic
	2	0.20–0.40	8.23	3.92	16	Saline-Sodic	8.81	6.52	40	Saline-Sodic

[1]Classification of salt-affected soils (Bohn et al. 1985)
[2]Mossoró and Apodi are located in the state of Rio Grande do Norte, northeastern Brazil. EC_e = Electrical conductivity of the soil saturated paste

0–40 cm soil layer. Another problem of these soils where reject brine has been disposed of is the high values of pH (above 8.50), which can hinder the availability of plants to absorb important minerals such as P, Mg, Fe and Zn, which are unavailable or have decreased availability in soils with pH above 7.5.

It is important to point out that, despite the restriction on the use of reject brine, its safe utilization depends on the practices and management strategies adopted, which include the selection of tolerant plants, mixture with fresh water, leaching fraction applied, etc.

2.3 Potential Agricultural Use of Reject Brine

Due to the large number of reverse osmosis water treatment plants installed in northeastern Brazil, studies are needed to enable the proper disposal of the waste generated (Oliveira et al. 2017). Alternatives of use of the reject brine are being studied, such as the cultivation of halophyte species like saltbush (*Atriplex nummularia* L.). For being native to arid regions, this species adapts well to the climatic conditions of northeastern Brazil, managing to produce a large amount of phytomass.

In developed countries, reject brine is usually discharged into the oceans, but other disposal options such as evaporation ponds, reduction of reject brine volume with the cultivation of aquatic plants, percolation ponds and irrigation of halophyte plants have been studied. In the USA, the reject brine is used in the irrigation of several crops, but according to Mickley (2004), this requires a lot of land available, and the reject brine is usually mixed with good-quality water to reduce the concentration of salts, being limited by the availability of good-quality water for dilution, climate, and soil absorption rates. In addition, it can be used in leisure areas such as lawns, parks, golf courses, open spaces, and green belts for soil conservation and environmental preservation.

Riley et al. (1997) considered the cultivation of halophyte plants as the best option to dispose of reverse osmosis reject brine. Other authors such as Dubon and Pinheiro (2001) also observed promising results when investigating the growth of tilapia (*Oreochromis*) in highly saline waters. In addition to fish farming, shrimp farming and/or multi-cropping (the practice of growing two or more crops on the same area during a single growing season) have also been employed to make use of the reverse osmosis reject brine.

Another option for the desalination reject brine is its use in the composition of the nutrient solution to grow vegetables in hydroponic systems, as demonstrated in the study conducted by Dias et al. (2010). Hydroponic crops are advantageous when brackish water is used because, due to the absence of matric potential, the effects of induced drought are avoided, increasing plant tolerance to salinity (Soares et al. 2006).

According to Mickley (2004), the choice of the best option to dispose of the desalination reject brine must meet, among other factors, the local availability (land, compatibility of receiving waters, and distance), regional availability (geology, state laws, geography, and climate), reject brine volume, costs involved, public opinion, and permissibility.

Antia (2015) evaluated the feasibility of desalination projects for exclusive use in the irrigation of crops and concluded that, due to the annual fluctuation of income in most agricultural units, due to climate variations and commodity prices, it is difficult to justify the financial investment to install a reverse osmosis desalination unit to produce a constant rate of high-quality desalinated water. Tchiadje (2007) studied strategies to reduce water salinity by desalination on production of crops, such as rice, cotton and pepper, and concluded that the yields increased as water salinity decreased and, for many crops, a relatively small reduction in soil or irrigation water salinity (for instance, 0.5–5 g L^{-1}) was sufficient to increase yields by 25–75%. Therefore, it can be inferred that an agricultural unit can substantially increase profitability by partially reducing the use of desalination reject brine.

3 Management of Reject Brine: Case Study in a Family Farming Unit

3.1 Experimental Location and Description

The project was conducted in the Santa Elza rural settlement (5°06′50.29″ S; 37°31′9.86″ W), located in the rural area of Mossoró, Rio Grande do Norte, Brazil (Fig. 3).

The action included integrated and sustainable subsystems with the purpose of giving an agricultural use to the brine coming from the desalination: initially, the saline well water (EC = 1.9 dS m^{-1} and pH = 7.6) was pumped to the treatment plant, benefiting the families with drinking water (EC = 0.12 dS m^{-1} and pH = 6.8); the reject brine (EC = 3.2 dS m^{-1} and pH = 7.4) from reverse osmosis was then directed to two fish hatcheries built for the breeding of tilapia; the effluents from fish farming (EC = 3.88 dSm^{-1} and pH = 7.71) enriched in organic matter were used as a source of water and nutrition for the cultivation of forage plants and organic vegetables. Finally, the forage produced was used in the feeding and fattening of goats and/or sheep, closing the sustainable production system (Fig. 4).

3.2 Results

3.2.1 Tilapia Farming

In a four-month cycle, 400 tilapias with an average weight of 630 g were collected from each hatchery, increasing family income and protein supply. The average feed conversion rate found was 1.5:1, which is considered high by Lovshin (1997), who

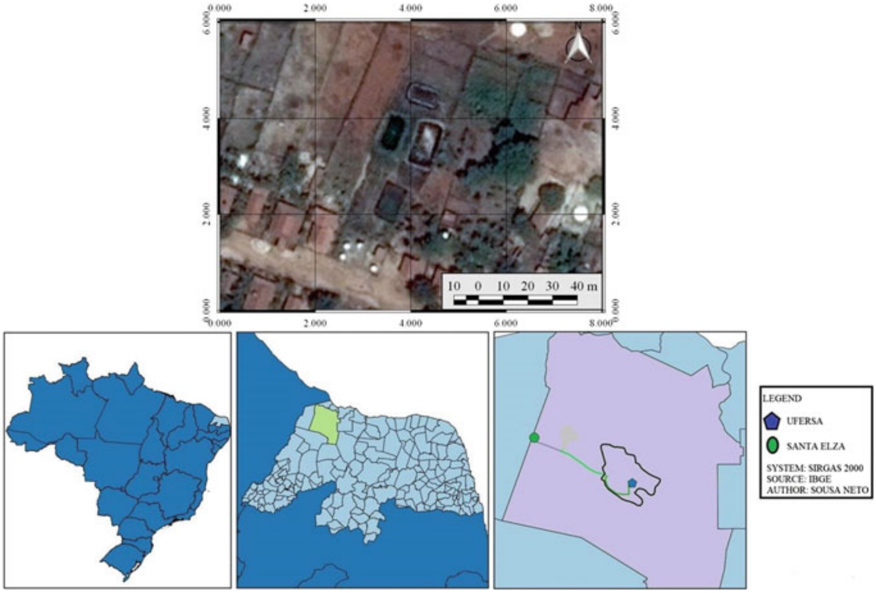

Fig. 3 Location of the Santa Elza settlement and the rural community Serra Mossoró, Mossoró, Brazil. *Source* Modified from Google Maps

states that it is essential to obtain a high-feed conversion rate, so that the intensive system of tilapia farming be economically viable. Within the limits of tolerance, tilapia grows and reproduces in brackish and salty waters, adapting to low levels of dissolved oxygen content, and coexists in a wide range of water acidity and alkalinity, tolerating high concentrations of toxic ammonia compared to most fish.

3.2.2 Production and Quality of Vegetables Fertigated with Fish Farming Effluent

The yields and nutritional quality of the main vegetables cultivated and irrigated with fish farming effluent were quantified (Table 5).

Although crop yield was reduced due to the salinity of the effluent water used in the fertigation of these vegetables, yield losses are economically acceptable considering the water restrictions in the region. Santos et al. (2012) concluded that there is a relative reduction of 10% in the production of arugula when irrigated with highly saline water (3.5–5.5 dS m^{-1}). However, the relative yield loss depends on crop tolerance to salinity. For example, lettuce and beet crops have threshold salinity of 1.3 and 4.0 dS m^{-1}, respectively, being salt-sensitive and salt-tolerant species, respectively. However, there are beet cultivars that tolerate water salinity above 4 dS m^{-1} (Lv et al. 2019) and other crops like that can tolerate salinity of irrigation water of 7 (Jerusalem artichoke) and 9 dS m^{-1} (spinach) with only 11% tuber yield or no

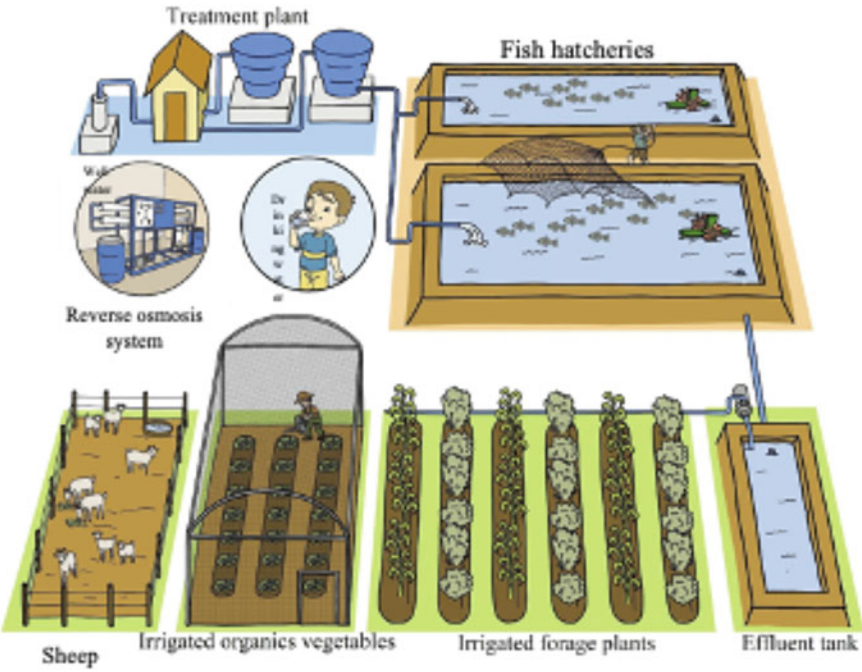

Fig. 4 Schematic representation of the integrated system used to desalinize well water, using the brine reject from desalination to raise fish. The mineral enriched water from fish production is then directed to an effluent tank and used to produce organic vegetables and salt-tolerant forage crops to feed small ruminants. The system is adjusted according to the salinity of the water input, of the local soil, and may integrate different crops according to the final salinity of the reject brine

Table 5 Average weekly yield of vegetables irrigated with fish farming effluent

Vegetables	Average weekly yield
Lettuce (*Lactuca sativa*)	50 units
Coriander (*Coriandrum sativum*)	45 bunches
Chives (*Allium schoenoprasum*)	26 bunches
Cabbage (*Brassica oleracea*)	40 bunches
Arugula (*Eruca sativa*)	30 bunches
Tomato (*Solanum lycopersicum*)	10.0 kg
Bell pepper (*Capsicum annuum*)	12.0 kg
Carrot (*Daucus carota*)	7.0 kg
Beet (*Beta vulgaris* subsp. *esculenta*)	6.0 kg

Table 6 Nutritional values of vegetables fertigated with fish farming effluent

Vegetable	Protein (g 100 g^{-1})	Vitamin C (mg 100 g^{-1})	Dietary fiber (g 100 g^{-1})
Lettuce	0.79	19.13	2.18
Coriander	17.20	10.12	35.50
Chives	3.60	55.12	2.60
Cabbage	3.20	95.26	3.61
Arugula	1.60	38.70	1.50
Tomato	0.83	28.10	1.16
Bell pepper	0.80	190.20	2.03
Carrot	1.41	5.83	4.23
Beet	1.36	4.70	1.98

reduction in shoot biomass or nutritional value, respectively (Dias et al. 2016; Ferreira et al. 2018). Research work recently presented at the INOVAGRI 2019 showed that spinach cultivars Raccoon and Gazelle can be cultivated with water of salinity as high as 13 dS m^{-1} in sandy medium without any significant loss in shoot biomass (J. Ferreira, personal communication).

The nutrients contained in the effluent from fish farming, due to the excretion of fish and the feed supplied in the nurseries, stimulate the vegetative growth of plants because of the improvement in soil fertility, especially the incorporation of organic matter (Andrade Filho et al. 2013). In addition, irrigation with effluent attenuates the deleterious effects of salt stress on plants.

The nutritional quality of vegetables grown under irrigation with effluent is similar to those found in the literature for organic or conventional vegetables (Table 6) (UNICAMP 2011). However, it is worth pointing out that the chemical composition of foods of plant origin depends not only on an isolated production factor, but on a set of factors and their interactions, such as fertilization, type of soil, occurrence of pests and diseases, climate, harvest, and genetic characteristics of the plant.

3.2.3 Growth, Yield, and Quality of Forage Plants Fertigated with Fish Farming Effluent

Table 7 shows the results obtained for the growth, yield, and forage quality variables of elephant grass, sorghum, and heirloom corn fertigated with fish farming effluent. In general, the dry matter yield found for the three forage species and grain yield for sorghum and heirloom corn were satisfactory and similar to those reported in the literature for these species.

Regarding the quality of the three forage plants, the average values recorded for crude protein (CP) were above the minimum necessary for ruminal fermentation to occur (Table 7), as described by Minson (1984), who established a minimum CP concentration of 7% for the process to occur satisfactorily.

Table 7 Average values obtained for growth, yield, and forage quality variables of elephant grass, sorghum, and heirloom corn fertigated with fish farming effluent from desalination reject brine

Elephant grass (*Pennisetum purpureum*)					
PH (cm)	TDM (ton ha^{-1})	CP (%)	Ca	Na	Cl
98.5	8.8	9.8	5.3	1.5	17.3
Sorghum (*Sorghum bicolor*)					
TDM* (ton ha^{-1})		CP (%)	GY (ton ha^{-1})	TSS (Brix)	JV (ton ha^{-1})
18.8		12.4	5.5	16.1	9.6
Heirloom corn (*Zea mays*)					
TDM* (ton ha^{-1})		CP (%)	GY (ton ha^{-1})	TSS (°Brix)	NGE (unit)
23.89		9.8	10.6	8.4	380.0

*Leaves + stem + head
PH = Plant height; TDM = Total dry matter; CP = Crude protein; Ca = Calcium; Na = Sodium; Cl = Chlorine; GY = Grain yield; TSS = Total soluble solids; JV = Juice volume in the stem; NGE = Number of grains per ear

The yield and quality of elephant grass, sorghum, and heirloom corn found are consistent with the average values reported in the literature (Minson 1984; Albuquerque et al. 2012; Vale and Azevedo 2013). This indicates that, despite the high salinity of the effluent, the yield and forage quality of the species were not reduced. Both yield and forage quality are related to the tolerance of the species to salinity and especially to the nutritional supply, mainly of organic matter, provided by the effluent. Although grasses are, in general, more tolerant than dicots to salinity, legume crops are higher in crude protein (CP) than grasses and may tolerate high salt concentration in irrigation water. For instance, alfalfa was reported to have from 20–30% CP and maintains its mineral composition and antioxidant capacity when irrigated with waters of salinity up to 24 dS m^{-1} (Ferreira et al. 2015). Another study with 15 alfalfa populations reported that biomass decreased to 50% of control when irrigation water had an ECiw of 18.3 dS m^{-1} with greater reduction at 24 dS m^{-1} (Cornacchione and Suarez 2017). Alternatively, forage trees with vigorous growth and tolerance to salinity (e.g., *Leucaena leucochepala*) may be evaluated under irrigation with brine deject.

4 Final Considerations

Desalination of saline and brackish waters by reverse osmosis benefits rural communities in the Brazilian semiarid region, but there is an environmental concern about the disposal of reject brine, due to its potential negative impacts on the environment if not properly managed.

Studies indicate that there is technical, economic, and socio-environmental feasibility for the use of desalination reject brine in family agricultural production, especially when using integrated and sustainable production systems. The use of reject brine for agricultural purposes can be profitable in rural communities and settlements while contributing to environmental conservation of soil and water resources. However, one must consider the salinity of the water input for desalinizers and of the local soils where the reject brine will be applied to grow agricultural and horticultural crops.

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