BIOSALINE AGRICULTURE IN THE BRAZILIAN SEMI-ARID REGION: WHAT IS POSSIBLE?

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ABSTRACT: Biosaline agriculture can be defined as the sustainable agricultural production using brackish waters and salt-affected soils. It contributes to the production of food, fodder, wood, among other products, especially in dry regions. But what would be the potential of this activity in the Brazilian semi-arid region? To answer this question, we used the database of brackish groundwater in the State of Ceará (6,284 wells) and defined the suitability of these waters based on the following criteria: water availability (discharge and well-functioning time), salinity of the water, crop water demand, and salinity threshold. The following systems were tested: halophytes, maize (full and supplemental irrigation), forage cactus, coconut and cashew trees. Forage cactus showed the highest percentage of suitability (41.3%) followed by supplemental irrigation of maize (36.8%). More than 90.0% of the water sources did not reach the salinity threshold for halophytes and coconut trees, but almost 70.0% of wells do not have enough water to irrigate 1.0 ha of these crops. Therefore, the brackish waters of the crystalline aquifer have a high potential for family farming in the Brazilian semi-arid region. This new approach can also be used by farmers, making it possible to define the potential of brackish waters and to choose the most sustainable systems for biosaline agriculture.
KEY WORDS: Biosalinity, Tropical dryland, supplemental irrigation, forage cactus, coconut.

AGRICULTURA BIOSSALINA NO SEMIÁRIDO BRASILEIRO: O QUE É POSSÍVEL?

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RESUMO: A agricultura biossalina pode ser definida como a produção agrícola sustentável utilizando-se águas salobras e solos afetados por sais. Ela contribui para a produção de alimentos, forragens, madeira, entre outros produtos, principalmente em regiões secas. Mas qual seria o potencial dessa atividade no semiárido brasileiro? Para responder a essa questão, utilizamos o banco de dados de águas salobras subterrâneas do Estado do Ceará (6.284 poços) e definimos a adequação dessas águas com base nos seguintes critérios: disponibilidade hídrica (vazão e tempo de bom funcionamento), salinidade da água, a demanda hídrica da cultura e o limite de tolerância à salinidade. A palma forrageira apresentou o maior percentual de adequação (41,3%) seguida da irrigação suplementar de milho (36,8%). Mais de 90,0% das fontes hídricas não atingem o limite de salinidade para halófitas e coqueiro, porém quase 70,0% dos poços não têm água suficiente para irrigar 1,0 ha dessas culturas. Portanto, as águas salobras do aquífero cristalino apresentam alto potencial para a agricultura familiar no semiárido brasileiro. Essa nova abordagem pode ser utilizada por agricultores, possibilitando definir o potencial das águas salobras e escolher os sistemas mais sustentáveis para a agricultura biossalina.

PALAVRAS-CHAVE: Biosalinidade, terra seca tropical, irrigação suplementar, palma forrageira, coco.

INTRODUCTION

Low rainfall and high evaporation and evapotranspiration rates cause scarcity of water resources in arid and semi-arid regions (MACEDO et al., 2010; ARAÚJO et al., 2019). Under these conditions, it is necessary to develop strategies to cope with the climate, including the sustainable use of brackish groundwater (CARVALHO et al., 2017).

Therefore, it is essential to know the quantity and quality of these water sources, as well as the water demand and salt tolerance of the production systems (LESSA et al., 2023). In this context, biosaline agriculture emerges, which can contribute to the sustainable production of food, fodder, wood, and several other products, with the use of saline resources (soil and water), particularly in semi-arid regions (MASTERS et al., 2007; SILVA et al., 2015; CAVALCANTE et al., 2021). However, one of the limiting points is the low flow of wells with brackish water, particularly those located in the crystalline basement of the Brazilian semi-arid region (SILVA et al., 2007).

In this context our question is: which type of biosaline agriculture system would have more potential in this region? So, the objective of the present work was to answer this question, taking into account the aspects of the wells (water availability and salinity) and production systems (water demand and salt tolerance).

MATERIAL E METHODS

The research was carried out in a number of wells with brackish water in the State of Ceará, with the aid of a groundwater database. We used the database of brackish groundwater in the State of Ceará (6,284 wells with water electrical conductivity - EC $\geq$ 0.8 dS m^{-1} and discharge rate - Q $\geq$ 0.5 m^3 h^{-1}) and defined the suitability of these waters based on the following criteria: 1. water availability (discharge rate and well- functioning time); 2. EC; 3. water demand of the crop; 4. salinity threshold of the crop system.

The following systems were tested: halophytes, maize (full and supplemental irrigation), forage cactus, coconut, and cashew trees. Salinity thresholds were defined for the production systems, as follows: a) Full irrigation of halophytes - 11.4 dS m^{-1} (PORTO et al., 2006; COSTA & BONILLA, 2016); b) Full irrigation of maize - 1.7 dS m^{-1} (AYERS & WESTCOT, 1999; LACERDA et al., 2011); c) Supplemental irrigation of maize - 3.2 dS m^{-1} (Adapted from LACERDA et al., 2011; BARBOSA et al., 2012; CAVALCANTE et al., 2021); d) irrigation of forage cactus – 3.0 dS m^{-1} (FONSECA et al., 2019; SANTOS et al., 2020); e) Irrigation of coconut orchards in sandy soils – 6.0 dS m^{-1} (FERREIRA NETO et al., 2002; MARINHO et al., 2005); f) Irrigation of cashew orchards in sandy soils – 5.0 dS m^{-1} (GUILHERME et al., 2005; ARAÚJO et al., 2014).

The minimum necessary discharge rate were also defined, as follows: a) Full irrigation of halophytes - 4.0 m^3 h^{-1}; b) Full irrigation of maize - 5.0 m^3 h^{-1}; c) Supplemental irrigation of maize - 2.50 m^3 h^{-1}; d) Full irrigation of forage cactus - 2.0 m^3 h^{-1}; e) Irrigation of coconut orchards in sandy soils - 6.0 m^3 h^{-1}; f) Irrigation of cashew orchards in sandy soils - 3,2 m^3 h^{-1}. For all cases, a well operating time of 6 hours and a leaching fraction of 20% were considered.

The wells were classified as suitable or not suitable for the conductivity of the water and for the discharge of the well and later georeferenced maps were prepared using the Quantum GIS 3.22 program (QGIS DEVELOPMENT TEAM, 2022).

RESULTS AND DISCUSSION

Data analysis showed that for the irrigation of halophytes for an area of 1.0 ha (Figure 1), 2,113 wells (33.7%) are adequate for both EC and water availability, 29 wells (0.5%) only have adequate discharge rates, 4,063 wells (64.6%) only have adequate electrical conductivity, and 79 wells (1.2%) do not have suitable salinity or water availability.

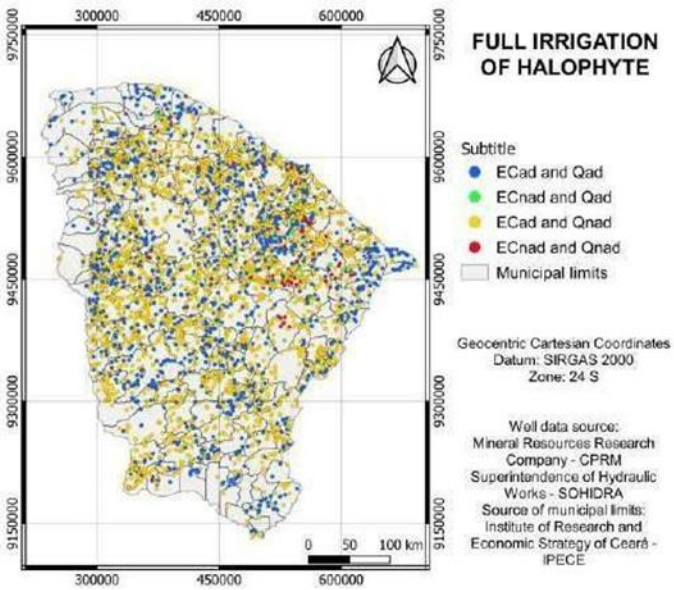

Figure 1. Potential of brackish groundwater in the State of Ceará (Northeast Brazil) for full irrigation of halophyte, based on the threshold electrical conductivity of the irrigation water (EC) and discharge rate (Q). ECad: adequate electrical conductivity; ECnad: inadequate electrical conductivity; Qad: adequate discharge; Qnad: inadequate discharge.

Halophytes constitute the plant system with the highest tolerance to salinity among those analyzed, and can be irrigated with high salinity water, notably in soils with good natural drainage (PORTO et al., 2006; COSTA & BONILLA, 2016). Halophytes can withstand high levels of salinity, while almost 99% of other plant species (glycophytes) have some level of sensitivity to salts (FLOWERS et al., 2010; HOLGUIN PEÑA et al., 2021). Halophytes also show good adaptability to arid and semi-arid regions and can be cultivated under rainfed farming or in saline soils, and many species can be used as forage, such as Atriplex spp., Salicornia spp. and Distichlis palmeri (MASTERS et al., 2007; PANTA et al., 2014; GHEYI et al., 2022). However, our data showed that about 65% of the wells with brackish water do not have enough water volume to irrigate an area of 1.0 ha with halophyte plants, although more than 95% have no salinity restriction.

For full irrigation of maize, in an area of 1.0 ha (Figure 2A), only 794 wells (12.6%) have adequate EC and Q, 839 wells (13.3%) only have adequate Q, 1879 wells (30.0%) only have adequate EC, and 2,772 wells (44.1%) have salinity above the threshold and do not reach the minimum discharge required for the crop. For supplemental irrigation of maize, for the area of 1.0 ha (Figure 2B) 2314 wells (36.8%) fit according to EC and Q, 825 wells (13.1%) only have adequate discharge, 2175 wells (34.6%) only have adequate electrical conductivity, and 970 wells (15.5%) are not suitable due to the high salinity and low discharge rate.

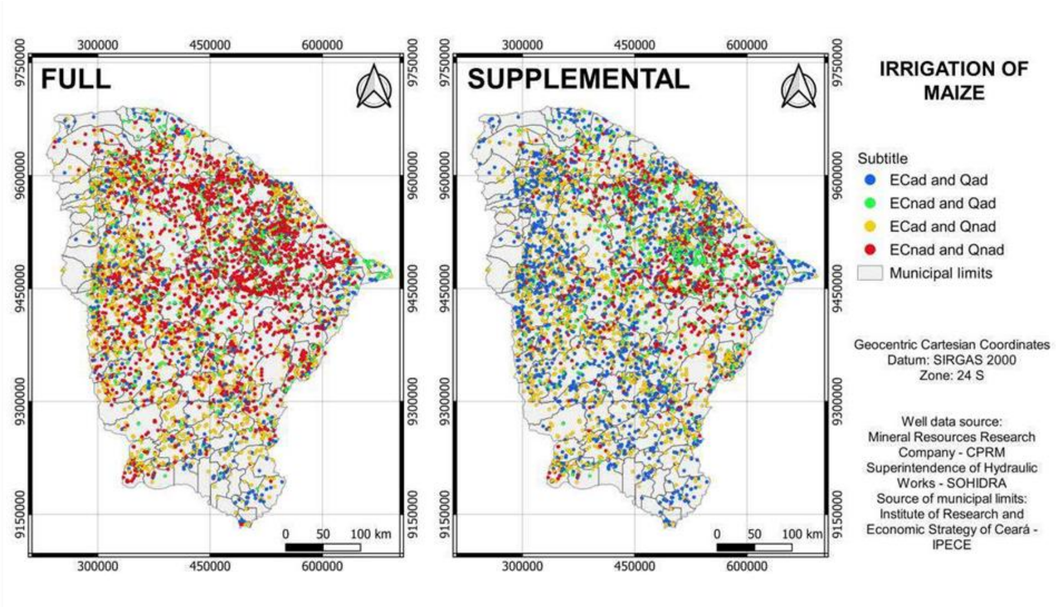

Figure 2. Potential of brackish groundwater in the State of Ceará (Northeast Brazil) for full irrigation (A) and supplemental irrigation (B) of maize, based on the threshold electrical conductivity of the irrigation water (EC) and discharge rate (Q). ECad: adequate electrical conductivity; ECnad: inadequate electrical conductivity; Qad: adequate discharge; Qnad: inadequate discharge.

Annual crops are also characterized by relatively high-water demand and varying degrees of salt tolerance (AYERS & WESTCOT, 1985; RIBEIRO et al., 2020; DOURADO et al., 2022). Among the annual species studied, maize is the most salt-sensitive (AYERS & WESTCOT, 1985; BARBOSA et al., 2012) and has the highest water requirement. For this crop, it was observed that only 13% of the wells are adequate for the cultivation of 1.0 ha under full irrigation, while 87% are limited by low discharge rate, high salinity, or both (Figure 2). However, when supplemental irrigation is used, the numbers are much more positive, reaching a level of adequacy of about 37%. In the context of biosaline agriculture, supplemental irrigation can reduce the losses of rainfed agriculture, especially in periods of dry spells, and is a decisive tool to deal with the limitations of the water availability in semi-arid zones both currently and when considering the future risks associated with global climate change (CHAUHAN et al., 2008; NANGIA et al., 2018). In our study, the systems with supplemental irrigation of maize with brackish water resulted in larger irrigable areas than for the cultivation of halophytes.

In the irrigation of forage cactus (Figure 3A) for an area of 1.0 ha, 2,594 wells (41.3%) present adequate EC and Q, 1,108 wells (17.6%) only have adequate Q, 1,733 wells (27.6%)

only have adequate EC, and 849 wells (13.5%) do not have adequate EC or Q. For the management of coconut irrigation in an area of 1.0 ha, 19.5% (1,225 wells) have adequate EC and Q, 1.4% (88 wells) have adequate Q only, 7.9% (499 wells) do not have adequate water electrical conductivity or discharge, and 71.2% (4472 wells) are limited by low water availability (Figure 3B).

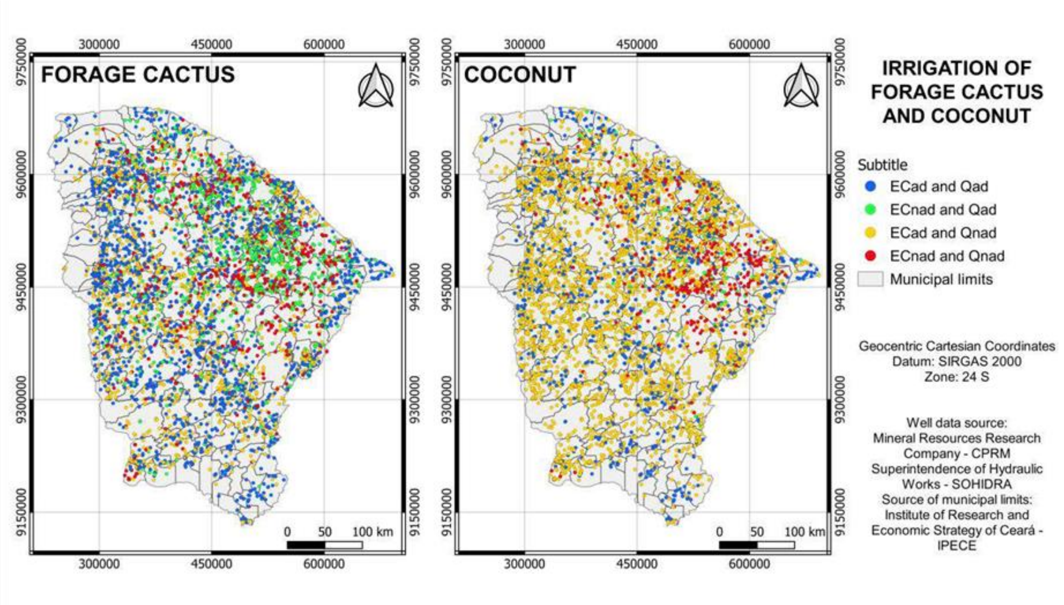

Figure 3. Potential of brackish groundwater in the State of Ceará (Northeast Brazil) for forage cactus (A) and coconut irrigation (B) in 1,0 ha, based on the threshold electrical conductivity of the irrigation water (EC) and discharge rate (Q). ECad: adequate electrical conductivity; ECnad: inadequate electrical conductivity; Qad: adequate discharge; Qnad: inadequate discharge.

Plant production systems with lower water requirements presented the best results (Figure 3A), even with moderate tolerance to salt stress. The forage cactus, a species with CAM metabolism (BORLAND et al., 2009; CUSHMAN et al., 2015), contrasted with the coconut palm trees, presenting adequacy of salinity and water availability of 41%, while coconut reached only 19.5%. Therefore, for perennial crops, it is recommended that species with low water demand should be used. For forage cactus (*Opuntia fícus*, *Nopalea cochenillifera*, *Opuntia* sp., *Opuntia stricta*) the total annual irrigation does not exceed 200 mm, with a low salt load applied to the soil during the dry season. Forage cactus is an important energy source for animal feed, as it has a high content of carbohydrates, total digestible nutrients, and water (COSTA et al., 2012; ROCHA Filho et al., 2021; RAVARI et al., 2022), and can also be component of multiple systems involving the use of brackish water and fish or in systems intercropped with gliricidia and other plant species (MIRANDA et al., 2019; SILVA BRITO et al., 2020; ARAÚJO et al., 2021).

For irrigation of cashew (Figure 4) in an area of 1.0 ha, 35.1% (2208) of the wells have adequate EC and Q, 5.0% (316 wells) do not have adequate EC, but have adequate Q, 9.7%

(608 wells) do not have adequate EC or Q, while 50.2% (3152 wells) are unproductive due to low water availability.

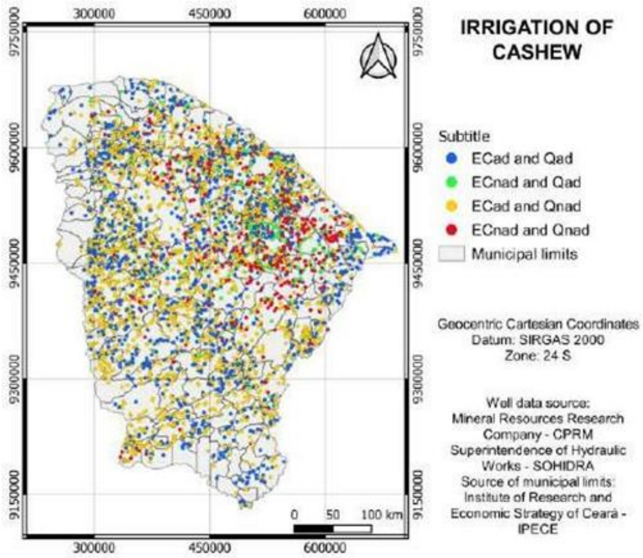

Figure 4. Potential of brackish groundwater in the State of Ceará (Northeast Brazil) for cashew irrigation in 1,0 ha, based on the threshold electrical conductivity of the irrigation water (EC) and discharge rate (Q). ECad: adequate electrical conductivity; ECnad: inadequate electrical conductivity; Qad: adequate discharge; Qnad: inadequate discharge.

The cashew crop has great social and economic importance, due to the multiple products obtained (BRAINER & VIDAL, 2018), and to adaptability to rainfed conditions and moderate salt tolerance (BEZERRA et al., 2007). This crop is one of the main sources of income generation for small farmers in the semi-arid region (SILVA, 2017). It is noteworthy that according to Bezerra et al. (2007) only 1% of cultivated hectares in the world are irrigated. However, irrigation allows for an increase in the production of chestnuts and the crop's peduncle (LIMA et al., 2016). The low discharge rates of wells with brackish water limit the size of orchards with this crop, as demonstrated in this study. In addition, the shallow soils in areas of the crystalline basement limit the implantation of orchards with cashew and coconut trees.

CONCLUSIONS

Our results demonstrate that tolerance of crops to salinity is important, but it is not the only option to cope with salinity problems in Brazilian semi-arid region. More than 98.3 and 90.7% do not reach the salinity threshold for halophytes and coconut trees, respectively, but 65.8 and 71.2% of wells do not have enough water productivity to irrigate an area of 1.0 ha of these crops. Otherwise, plant production systems with lesser water requirements (forage cactus and supplemental irrigation,) presented higher potential for biosaline agriculture than more salt-tolerant species.

Forage cactus showed the highest percentage of adaptability (41.3%) followed by supplemental irrigation of maize (36.8%). Therefore, the brackish waters of the crystalline aquifer have a high potential for family farming in the Brazilian semi-arid region. These results demonstrate that the use of quantitative and qualitative data generates more realistic information related to the potential of brackish water for agricultural purposes, and this type of evaluation should be recommended to other semi-arid regions worldwide. This evaluation method can also be used by farmers, making it possible to define the potential of brackish waters and to choose the most sustainable systems for biosaline agriculture.

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