Environmental, Agricultural, and Socioeconomic Impacts of Salinization to Family-Based Irrigated Agriculture in the Brazilian Semiarid Region

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Abstract Soil salinity is one of the major abiotic factors causing a serious threat to global food security, mainly in arid and semiarid regions. Salinity brings socioeconomic impacts associated with low crop productivity and devaluation of agricultural lands. In this chapter, we approach agricultural, environmental, and socioeconomic

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impacts of soil salinization. We also report two case studies from irrigated areas of the Brazilian semiarid, where previously cultivated lands were abandoned due to increased soil salinity. A survey of the published literature showed that soil salinity became a global problem that is accelerated by human activities such as deforestation and lack of irrigation management. We conclude that socioeconomic impacts of soil salinity in agricultural lands translate directly as either loss or reduction of crop yield, profit margins, unemployment, and/or reduction of land commercial value in the long run due to soil infertility. Only governmental and private institutions have the financial capability to intervene and help small farmers to counteract this bleak scenario, including water and soil management improvement, to alter the future and improve quality of life of small farmers in the Brazilian semiarid region.

Keyword Peasant · Food security · Agricultural revenues · Droughts · Rural services

1 Salinization: A Threat to Agriculture and Food Security

Climate change affects mainly the arid and semiarid regions of the planet, making it difficult to impossible for farmers to achieve food security and limiting agricultural production in areas where rain is scarce or lacking. Food security only exists when all people have physical and economic access to nutritious and safe food resources at all times (World Food Summit 1996).

Thus, developmental policies for food security become essential to all who live in environments with low rainfall and vulnerable to climate changes. These policies may include social technologies of coexistence with the semiarid and, when appropriate, the development of efficient irrigation methods using alternative water sources such as treated domestic sewage effluents, drainage water, dams, underground dams, and water from tubular wells. Generally, these water sources contain high concentrations of salts that can salinize irrigated areas and hamper agricultural production. This situation can be aggravated by edaphoclimatic conditions and improper management practices applied to the agricultural areas (Medeiros et al. 2017; Brito et al. 2017).

In extreme cases, soil salinity can reduce the biodiversity of a region drastically and salts deposited on the soil surface may be transported by wind or by surface flow and salinize nearby water bodies and soils. Consequently, local vegetation growth

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will be hindered by the effects of salt on both soil and plants, thus affecting livestock and wild life due to the lack of natural pasture and arboreal shelter (Amorim and Porto 2001).

Socioeconomic impacts due to the salinization of irrigated areas are more pronounced in family-based agricultural areas. Lack of technical knowledge on saline water management by most farmers living in afflicted areas has led to increased soil salinization in a short term. In addition, family farmers have only one irrigated plot to perform agriculture and trade. This plot, once salinized beyond the threshold of most agricultural and horticultural crops, makes agriculture unfeasible for them and, because of the high cost of recovery of salinized soils, leads to abandonment of properties (Gheyi et al. 2016). On the other hand, agribusiness enterprises have the financial capability to abandon their salinized lands and move to newly purchased rural properties to maintain their profit margins on the commercialization of high-value agricultural products.

Salinity and periodic droughts are the most important issues for local farmers living in arid and semiarid areas of the world. Soil salinity is a serious global problem that threatens agricultural productivity with at least 20% of all irrigated areas being salt-affected, but with some estimates being as high as 50% (Pitman and Läuchli 2002). Estimates predict that 50% of all arable land will be impacted by salinity by 2050 (Butcher et al. 2016). This process is accelerated by human activities such as deforestation, use of saline water to irrigate crops, and subsequent inadequate irrigation management.

In this chapter, we discuss aspects related to environmental, socioeconomic, and agricultural impacts of soil salinization that threaten global food security, especially in arid and semiarid areas. Additionally, we report two case studies conducted in irrigated perimeters in Brazil where agricultural lands were abandoned due to salinization.

2 Impacts of Salinization

Several irrigated areas in Brazil and worldwide are affected by salts naturally originated in the soil or added by irrigation water, especially in arid and semiarid environments. Salinity impacts small and large agricultural communities through agricultural, environmental, and socioeconomic aspects.

2.1 Impacts on Agriculture

Soil salinization reduces plant growth, agricultural productivity (Fig. 1a), and fruit size, number, and quality (Machado and Serralheiro 2017; Ferreira et al. 2019). Water and soil Salinity limit the choice of crops that can be farmed, as the majority of our staple agricultural and horticultural crops are susceptible to salinity and may suffer a

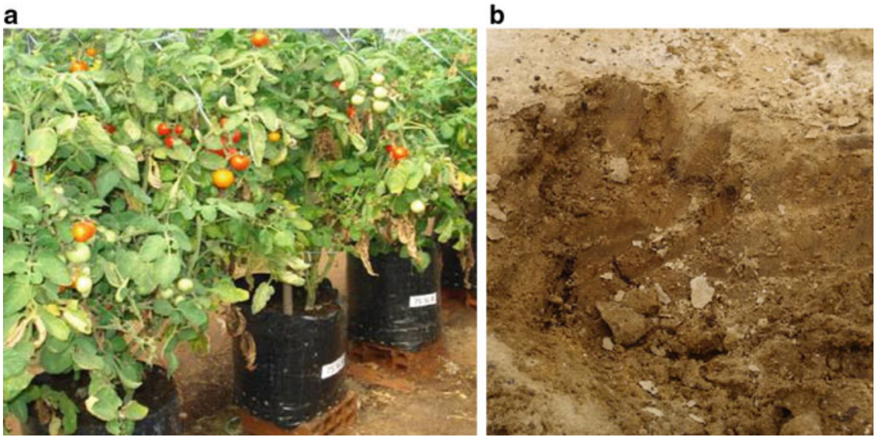

Fig. 1 Impacts of soil salinization: **a** Burn on cherry tomatoes caused by salinity and the consequent loss of fruit yield (Mossoró, Brazil). **b** Weakly aggregated soils caused by excess sodium in soil profile of irrigation district Baixo-Açu (DIBA), Ipanguaçu, Brazil. *Source* The authors

significant drop in yield even when irrigated with waters of low to moderate salinity. Excess sodium can destroy soil structure (Fig. 1b), causing infiltration problems, erosion, and nutrient losses.

Salinization leads to reduction of water quality for domestic use and irrigation, damage to rural property infrastructure such as buildings, roads, fences, underground pipes, and agricultural equipment due to corrosion caused by salts. Poor animal health and loss of the native flora and fauna lead to reduced land value (Tenison 2009).

Thus, salinity effects on plant production, soil, farming equipment and livestock impacts rural farmers at different rates, depending on their economic level and their access (or lack of it) to rural development strategies, which are usually not available to low-income small farmers.

2.2 Environmental Impacts

The environmental impacts of soil and water salinity include the reduction of native vegetation (riparian forest and native forest) and biodiversity loss, decreased population of birds, and other wildlife due to lack of food and shelter, increased soil erosion, losses of aquatic fauna due to the absence of natural habitat, reduction of landscape aesthetic value that compromises recreational and tourist spaces (ecological parks and sanctuaries) and increased proliferation of colonizing species with undesirable changes in plant and landscape populations (Fig. 2).

Fig. 2 Predominance of salt-tolerant species such (*Blutaparon portulacoides* L.) that naturally colonizes salinized lands cultivated with banana trees (Burn on leaves indicates the effect of toxicity due to high salinity of the soil) irrigation district Baixo-Açu (DIBA), Ipanguaçu, Brazil. *Source* The authors

2.3 Social Impacts and the Local Economy

The impacts of increased soil salinity on the community social structure include the reduction of the aesthetic value of the landscape (Fig. 3), decreased agricultural revenue due to low crop productivity, and low commercial property value due to the

Fig. 3 Salinity induced by poor drainage and inadequate irrigation management. Irrigation district Baixo-Açu (DIBA), Ipanguaçu, Brazil. *Source* The authors

degradation of soil, environment, and lack of agricultural jobs that leads to population impoverishment. In extreme cases, this scenario results in rural exodus.

Tenison (2009) reported that soil salinization in family-based agricultural operations increases social pressure in the consolidation of rural property with a significant reduction in the availability of services in small rural towns. This problem results in increased costs of social assistance and public-income transfer policies in trying to reduce poverty and social inequalities. For this reason, many salinized lands are abandoned each year, triggering a process of mass migration to urban areas and, consequently, aggravating social problems such as unemployment, illiteracy, violence, and crime in affected areas. The reduction in crop yield caused by increased soil salinity and water scarcity increases poverty and reduces *per capita* income. The Brazilian Northeast region accommodates 22 million inhabitants, of which 9 million live in rural areas. The area has the lowest income rates in Brazil representing a GDP (gross domestic product) *per capita* of less than US$ 2,000/year or $5.50/day and the official Brazilian minimum wage (salary) was R$1,448.00/month (US$638.62/month or US$8,302.06/year) in 2015 (Aleixo et al. 2016). Some proposed measures to mitigate the salinity impact in family farms are the expansion and reform of rural advisory services, focusing on individual capacity building and leading to the development of multistakeholder strategies to promote adequate management practices of available resources, access to the market and, therefore, the sustainable use of the lands.

One must keep in mind that access to drinking water alone will not solve the socioeconomic situation of rural communities in the Brazilian semiarid (much like the situation of semiarid areas in other developing countries). When inequalities in water access conditions were assessed in the community of Cristais (Ceará state, Brazil), 31% of the households reported to earn less than official minimum wage per month, 37% of the household heads were illiterate, and 46% were retired or worked as pensioners and agricultural workers (Aleixo et al. 2016). Thus, besides drinking water, access to education, health services, and creation of jobs in afflicted rural communities is a must. In this sense, maybe the improvement and establishment of integrated agricultural systems using brine reject from water desalinization to generate animal protein (tilapia and small ruminant farming) for household consumption and commercialization may be part of the solution (Moura et al. 2016).

In the Brazilian semiarid, salinization (natural or anthropogenic) brings about social problems due to the yield losses of vegetables, grasses, cotton, and orchards. When these problems occur in irrigated perimeters, their effects contribute to the disorganization of the region's agro-food sector that affect the local economy and produce negative social effects on rural communities. Of course, this cannot be blamed only on natural causes, as it was evidenced during the severe drought of 2012–2015, which affected not only the Brazilian Northeast, but also the Southeast, including the states of São Paulo and Rio de Janeiro and even southern California. The lack of planning, proper infrastructure, accelerated population growth, and improper management of funds in Brazil (not uncommon in developing countries) led the Brazilian Southeast to a severe water scarcity similar to what would be seen in the Northeast (Slater 2019).

In Northeastern Thailand, Naing et al. (2013) evaluated the impacts of soil salinity on the agricultural production system and described socioeconomic conditions in areas affected by salts. Their results indicated that the reduction of productivity in crops due to salinization effects led to social tension, unemployment, and income reduction in all the locations studied. Additionally, the authors reported that large-scale soil salinization also affected smallholders, reducing their capability to produce staple crops and intensifying poverty. The authors concluded that although people are the main agents of secondary salinization, they are also their victims. Other studies involving lowland cropping systems in Northeast Thailand (Kabaki et al. 2003) indicated that low fertility of sandy soils in the region, along with frequent droughts, degradation and salinity are the main causes of low yield and, consequently, food safety problems for farmers.

In the United States, a study done by the NRCS-USDA (2012) indicated that soil salinity has become a major concern for counties of the upper James River watershed. The Natural Resources Conservation Service (NRCS), a branch of the United States Department of Agriculture (USDA) evaluated the potential economic impact of salinity in the upper James River, soils, and cropping patterns of the three top counties in the watershed (Brown, Spink, and Beadle Counties). The analysis of results indicated that saline impact in soils of the tri-county area was estimated to occur in 280 acres and lowered the average productivity of the four major crops raised in this area (corn, soybeans, spring wheat, and winter wheat) in 30%. The economic impact of this productivity decrease in the tri-country area was estimated at $26.2 million.

3 Salinity Affecting Irrigation Projects: Local Case Studies

3.1 Irrigated District of Baixo-Açu, Rio Grande Do Norte, Brazil

The first case study involves the project Irrigation District Baixo-Açu (DIBA), the body that brings together water users of the irrigated perimeter Low-Açu, founded on March 5, 1997. DIBA has the purpose of managing, operating, and maintaining the irrigation and drainage infrastructure commonly used in that perimeter. The major crops produced in this perimeter by family-managed farms are bananas, coconut, papaya, and zucchini.

A study conducted by Barreto (2019) shows that, after 23 years after the foundation of DIBA, from 20–30% of the lots were salinized due to the absence of planning to avoid the accumulation of salts in the soils, which will be discussed below (Fig. 4).

Figure 5 shows a schematic design with some land parcels managed by DIBA indicating that the main cause of soil accumulation of this irrigated perimeter, characterized by high evapotranspiration and superficial water table, is the absence of a drainage system to leach soil salts beyond the root zone. In Fig. 5a, the yellow line

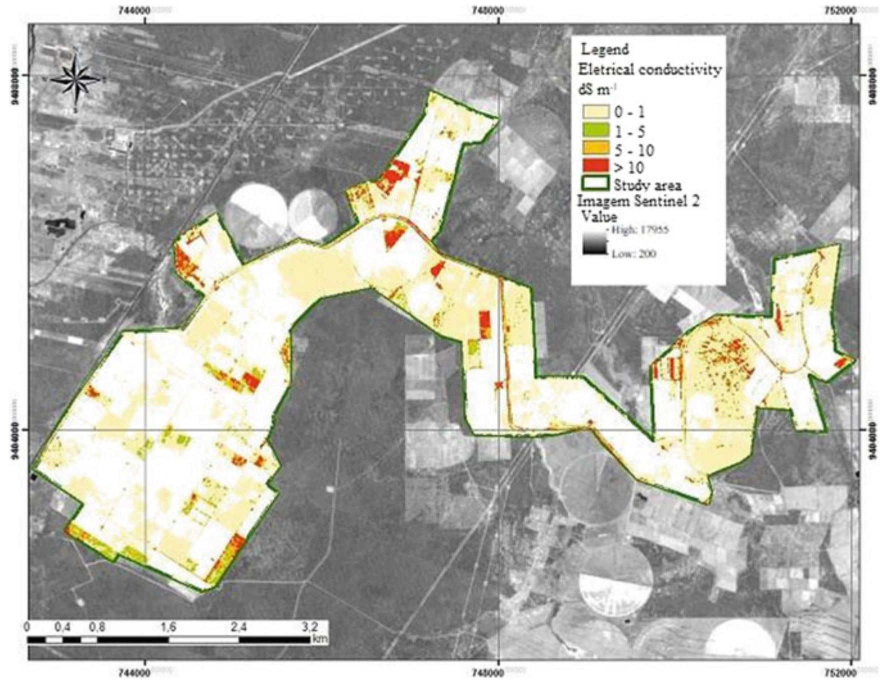

Fig. 4 A map of the Baixo-Açu project irrigation district soils with a high-risk potential for salinization (EC > 4 dS m^{-1}). *Source* Barreto (2019)

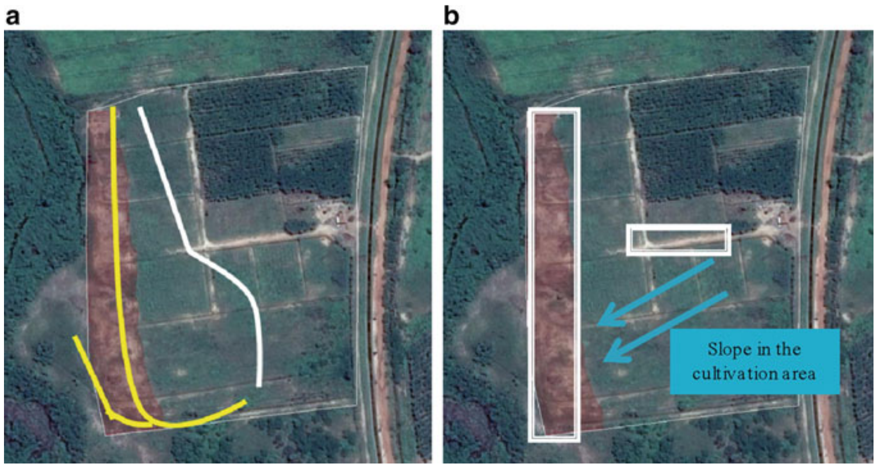

Fig. 5 Salinization of the parcels of the irrigated district of Baixo Assú (DIBA). **a**–Yellow lines show where the drainage system should be installed and white line show the progression of salinity. **b**–Blue lines show direction of the slope. *Source* Modified from Google Maps

indicates where the drainage system should be installed, but the area became a salt accumulation basin, being clearly identified by the presence of a white crust (salt) on the surface and of blackened spots (sodic humates). The white line shows the advance of salinity in the low areas.

Figure 5b shows the slope in the cultivation area. The soil of this area is classified as Cambissolo (EMBRAPA 2013), also known as inceptisol by soil survey staff (2014), which is naturally deficient in micro-drainage and, possibly, with a high degree of degradation (PST above 15%).

The absence of the macro- drainage of the area results in the accumulation of salts in the crop root zone, even using low electrical conductivity water (CE $<$ 0.6 dSm^{-1}), because semi-prevented drainage raises the ground level of the lower area, accumulating salts on the soil surface by capillary action.

3.2 Apodi Valley, Rio Grande Do Norte, Brazil

The rural producers of DIBA have a different profile in relation to peasants who practice irrigated agriculture in the "Sertão" of Apodi. In the irrigated perimeters, land ownership is varied, and farmers acquire land through purchase, exchanges, and leases, while Apodi farmers practice family farming, almost always in irrigated lands inherited from their parents. Although the succession system is carried out by sharing, the family nucleus remains preserved. In both cases, the advance of land salinization is evident and has severe social impacts in the agricultural production system, threatening food security of rural families.

In this second case study, the difficulties are more evident, since the farmers have a small financial capital to acquire new lands. In DIBA, producers work as employers. So, farmers often abandon their parcels because of the financial inability to pay accumulated debts. The low profitability is a consequence of the high cost of electricity and low productivity, resulting in the end of agricultural activities and in land abandonment.

In the Apodi valley, rice is the main crop but, according to farmers, the cultivated areas are decreasing each year due to the low productivity (Fig. 6).

In the Apodi valley, impoverished farmers must cope with soil infertility due to salinization because land ownership does not change easily and will probably pass from parents to their children through inheritance. The land use also changes and parcels where red rice was once cultivated become pasture for cattle during the rainy season.

In addition to the problem of salinization, drought also reduced the cultivated areas for rice production between the years of 2013 and 2017. It is worth noting that from 2012 to 2017, the Brazilian northeast went through the worst drought in 50 years. However, the rice yield per hectare reached approximately 7 tons in 2018 (Globo 2019), which is considered a good yield for the region. This high yield is attributed to the rainfall above average for the period.

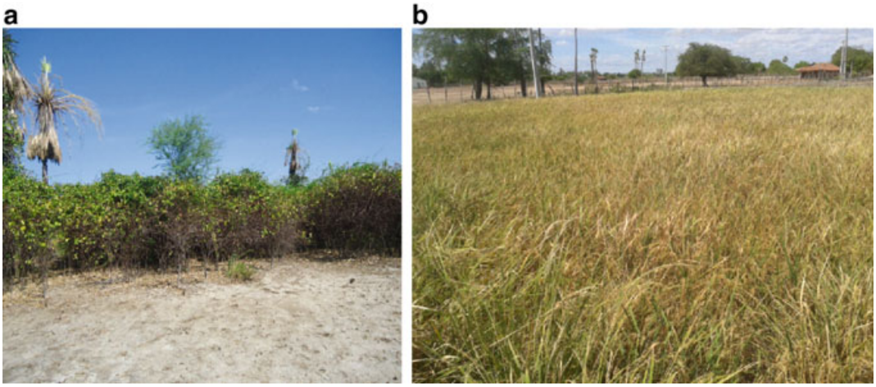

Fig. 6 Salinized soils–**a** and rice culture with characteristic symptoms of toxicity effect–**b**. Vazia da Salina, Apodi, Brazil. *Source* The authors

In both cases reported above, declining in agricultural production is leading to land abandonment, reducing rural population, and increasing unemployment. This problem impacts the local economy so that rural workers who do not have land ownership, but who develop agricultural activities, live an occupational duality: they work in agriculture part-time supplementing their income with non-agricultural activities. This reality often creates bigger problems when farmers reach the retirement age.

4 Final Considerations

Salinization of irrigated areas is one of the important issues for local farmers living in the arid and semiarid zones of the world. Soil salinity has become a serious problem around the world and this process is accelerated by human activities such as deforestation and poorly managed irrigation.

The socioeconomic impacts of soil salinity in an area of agricultural production are directly influenced by a reduced crop yield driven by salinity effects on plants and soil. These factors eventually lead to the loss of commercial value of agricultural land.

Irrigated perimeters face enormous problems of salt accumulation and therefore the degradation of water resources. Despite the lack of technical assistance, farmers continue their efforts to manage periodic droughts and to cultivate the land to increase food security for their families.

Salinity problems are more severe in irrigated areas with arid and semiarid conditions because insufficient precipitation to leach salts away from root zone, associated with increased evapotranspiration, severely limits crop growth and productivity. This scenario is seen especially when there is no management associated with irrigation and no agricultural practices that mitigate the negative effects of salt accumulation in soils leading to poor crop performance or death.

Governments, institutions, and the private sector should not only provide technical assistance for farmers, specially emphasizing water and soil management, but also should consider the proper investment in infrastructures for water storage and distribution that will be crucial to face unpredictable droughts in the dawn of global warming. The advisory services should focus their efforts in promoting the adoption of salt- and drought-tolerant crops, and the development of social technologies that could increase food production and ensure food and nutrition security throughout these regions.

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