Cah. Agric. 2025, 34, 14

https://doi.org/10.1051/cagri/2025012

Cahiers Agricultures

Available online at:
www.cahiersagricultures.fr

Resilience of semi-arid rural socio-environmental systems - Crossed points of view from Brazil and Africa / Résilience des systèmes socio-environnementaux ruraux semi-arides - Regards croisés Brésil et Afrique.
Coordonnateurs : Julien Burte, Eduardo SPR Martins, Marcel Kuper, Sami Bouarfa, Jean-Yves Jamin

ARTICLE DE RECHERCHE / RESEARCH ARTICLE

OPEN ACCESS

Agricultural dynamics in the semi-arid Northeast region of Brazil: issues for natural resources management and territorial governance

Isabelle Tritsch[1,2,9,*], Eric Scopel[2,3,9], Rafaela da Silva Alves[4], Rousilene Silva Nascimento Diniz[4], Samiramisthaís Souza Linhares[4], João Dehon de Araújo Pontes Filho[4], Diogenes Passos Fontenele[4], Francisco das Chagas Vasconcelos Júnior[4], Veronica Mitroi[5], Julien Burte[5,6], Xavier Augusseau[7] and Eduardo Sávio Passos Rodrigues Martins[4,8]

[1] CIRAD, UPR Forêts et Sociétés, Montpellier, France
[2] CIRAD, Research Institute of Meteorology and Water Resources (FUNCEME), Fortaleza, Brazil
[3] CIRAD, UPR AIDA, Montpellier, France
[4] Research Institute of Meteorology and Water Resources (FUNCEME), Fortaleza, Brazil
[5] CIRAD, UMR G-EAU, Montpellier, France
[6] CIRAD, UMR G-EAU, IAV Hassan II, Rabat, Maroc
[7] CIRAD, UMR TETIS, Montpellier, France
[8] Federal University of Ceará (UFC), Fortaleza, Brazil
[9] Université Montpellier, Montpellier, France

Abstract – Ceará State (Northeast Brazil) was recently affected by a severe multi-year drought (2012–2018) that had drastic societal consequences. The agricultural sector was particularly impacted and agricultural trajectories have evolved accordingly. The dairy sector has been strongly consolidated among family farmers, as seeming to offer greater resilience to drought than irrigated crops. However, the consequences of these important agricultural dynamics on natural resource management, and particularly water, have not been adequately studied. This study aimed to explore how agricultural trajectories have been transformed and how this has affected the sustainability of water, land, and forest resource management. It then suggests a territorial governance organization to discuss related issues and collectively try to solve them. This study emphasizes two main agricultural transformations: (i) the increase in mechanized permanent cropping systems substituting the traditional shifting agriculture system with forest fallow rotation, and (ii) increased fodder production through 'passive irrigation' in lowlands and infiltration areas around dams. These processes support a strong dynamic of individual small dam building. The main issues of these transformations in terms of natural resource management concern soil health in a regional context of high vulnerability to desertification, and the strong mobilization of water in lowlands and small individual dams. Since these dams are located upstream of the State's strategic dams, they weaken its water security and open the challenge of finding trade-offs between upstream-downstream regions, macro-micro water infrastructures and agricultural development-water supply. To contribute to meeting this challenge, three participatory governance platforms articulated from the State to the local territories are being tested in an attempt to negotiate collective trade-offs on the use of natural resources, decompartmentalize public action targeting rural territories, and promote a bottom-up approach to territorial development.

Keywords: natural resources management / agricultural transformations / participatory governance platform / dry lands / Brazil

Résumé – Dynamiques agricoles dans la région semi-aride du Nordeste brésilien : enjeux de gestion des ressources naturelles et de gouvernance territoriale. L'état du Ceará (nord-est du Brésil) a récemment été touché par une grave sécheresse pluriannuelle (2012-2018) aux conséquences drastiques

*Corresponding author: isabelle.tritsch@cirad.fr

pour la société. Le secteur agricole a été particulièrement affecté et les trajectoires agricoles ont évolué en conséquence. La filière lait s'est fortement consolidée auprès des agriculteurs familiaux, car semblant offrir une résilience à la sècheresse plus élevée que les cultures irriguées. Cependant, les conséquences de ces dynamiques agricoles sur la gestion des ressources naturelles, et particulièrement l'eau, ont été peu étudiées. Cet article vise à explorer comment les trajectoires agricoles ont été transformées et comment cela a affecté la durabilité de la gestion des ressources en eau, en sol et en forêt. Puis, il relate une expérimentation de gouvernance territoriale visant à résoudre collectivement les problématiques identifiées. Cet article souligne deux changements majeurs : i) l'essor des systèmes de culture permanente mécanisés remplaçant le système traditionnel d'agriculture itinérante en rotation avec une jachère forestière, et ii) l'augmentation de la production de fourrage par « irrigation passive » dans les bas-fonds et les zones d'infiltration autour des barrages. Ces processus soutiennent une forte dynamique individuelle de construction de petits barrages. Les principaux enjeux de ces changements en termes de gestion des ressources naturelles concernent la santé des sols, dans un contexte régional de vulnérabilité à la désertification, et une forte mobilisation des ressources en eau dans les bas-fonds et dans des barrages individuels. Ces barrages étant situés en amont des barrages stratégiques de l'Etat, ils fragilisent sa sécurité hydrique et ouvrent le défi de trouver des arbitrages entre amont-aval, infrastructures hydriques macro-micro et développement agricole-approvisionnement en eau. Pour y contribuer, trois plateformes de gouvernance participative, articulées de l'État aux territoires locaux, sont testées pour tenter de négocier des compromis collectifs sur l'usage des ressources naturelles, décloisonner l'action publique ciblant les territoires ruraux, et promouvoir une approche plus ascendante du développement territorial.

Mots-clés : gestion des ressources naturelles / transformations agricoles / plateforme de gouvernance participative / semi-aride / Brésil

1 Introduction

Brazil's northeast semi-arid region, also called the "Sertão", is the world's most populous dryland region, setting up many socioeconomic, environmental, and sustainability challenges, particularly in the context of climate change. Recently, the Ceará State has been affected by a severe multi-year drought (2012–2018) (Pontes Filho *et al.*, 2020) which has devastating consequences for water storage, agriculture, livestock, and industry. Several strategic reservoirs have reached a critical filling rate of less than 4%, causing serious problems for the human water supply and posing a major challenge to water resource management (Souza Filho, 2018). In 2016, of the 155 strategically monitored reservoirs in Ceará State, 39 were completely emptied; 42 reached their minimum water levels, requiring pumping systems to access water; and 52% of the state's municipalities experienced water supply disruptions (Martins and Magalhães, 2017). Agricultural production has been drastically affected whether irrigated or rain-fed, and the social and economic consequences have been dramatic, particularly because most (75%) farmers in Ceará are family farmers, and therefore particularly vulnerable (IBGE, 2017; Martins and Magalhães, 2017). This drought has placed water security, risk management, agricultural development, and territorial resilience at the centre of the state's political agenda (Souza Filho, 2018).

In response to this serious crisis, Ceará State has begun to implement an ambitious and technically innovative water infrastructure public policy called *Malha d'Água* (Water Grid) to strengthen the State's water security. This program aims to collect water directly from strategic reservoirs and redistribute it to the main urban and rural towns located upstream through a network of adductors. This policy is the fruit of the worldly dominant paradigm for addressing drought problems: an engineering paradigm that is oriented through big infrastructure projects, such as large dams, wells, and water transfers which are known in the region as the "fight against drought" paradigm (Cavalcante *et al.*, 2022). Nonetheless, a "*convivência com o semi-aride*" paradigm ("coping with drought" or "Co-existence with the Semi-aridity"), has emerged since the 1990s and has gained popularity during the last decade (Cavalcante *et al.*, 2022). This paradigm is based on the development of technological alternatives to strengthen the potential of the Caatinga biome (Caatinga is the native dry forest ecosystem from the Sertão region), seeking synergy between the environmental and social capital of the region.

In line with the co-existence of these two paradigms, and following the consequences of the recent multi-year drought, which the existing infrastructure was unable to prevent and contain, the Ceará State decided to complete the infrastructure *Malha d'Água* program with a cluster of multidisciplinary research-action projects, called "Sertões", to support stakeholders in a reflection on the current water governance, agricultural transformations and on the co-construction of sustainable territorial trajectories. These projects involved wide intersectoral reflections on territorial issues concerning natural resource management, particularly water. However, literature on the interrelations between water resources and agricultural and forest dynamics in the region is scarce (Burte *et al.*, 2020). Therefore, this study aimed to analyze how the agricultural dynamics of this semi-arid region have impacted water and forest resources, and vice versa, in the context of severe drought. Then, the challenges of the Sertões project being to support stakeholders in intersectoral water governance and natural resources management, this article suggests a territorial governance organization. It explains the social organization experimental initiatives introduced by the Sertões projects to attempt to collectively answer to the identified issues and co-construct sustainable territorial trajectories.

First, this paper revisits the evolution of agriculture in the context of the most recent multi-year drought. It then analyses the main agricultural transformations and their impacts on

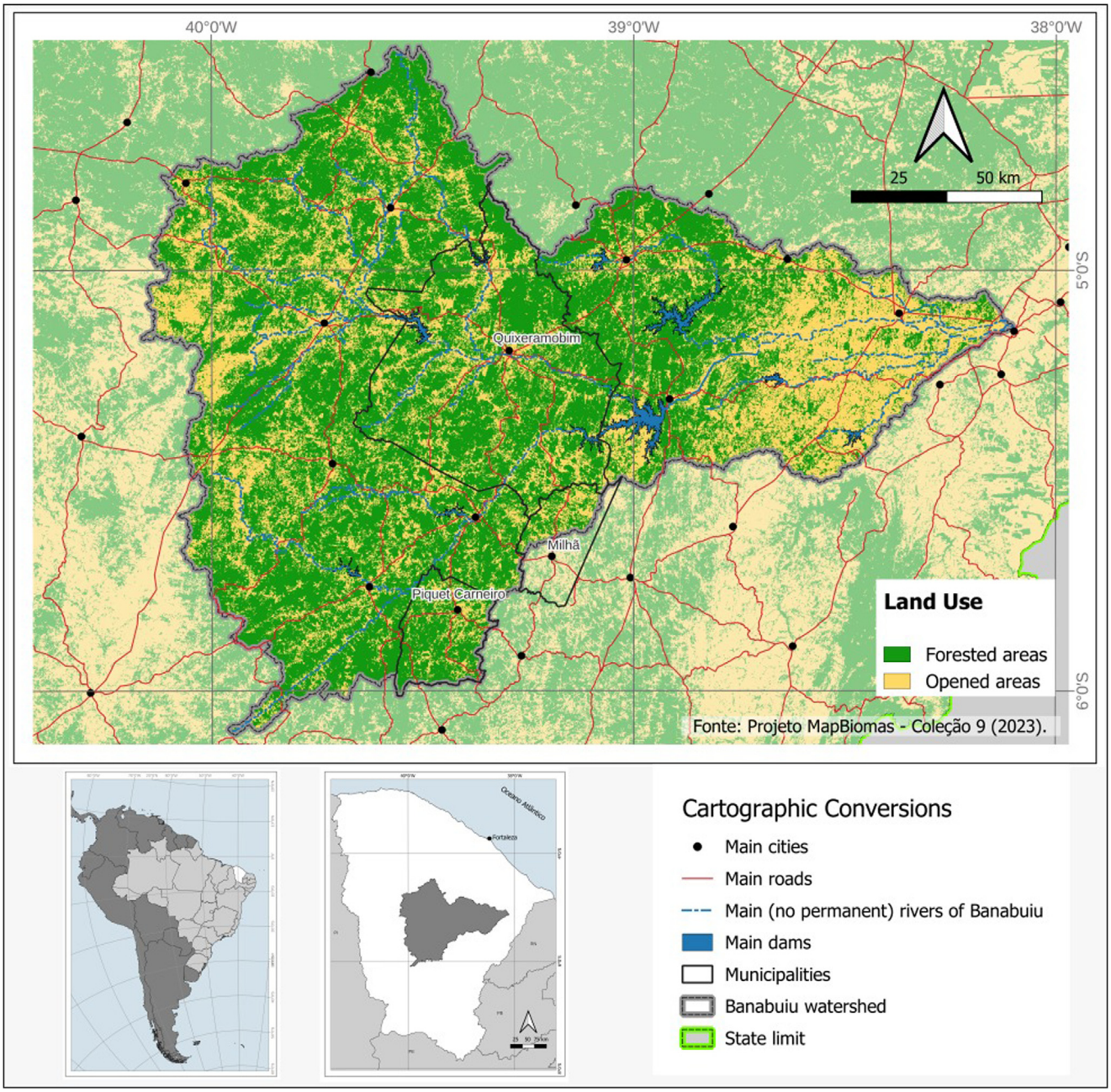

Fig. 1. Study site.
Fig. 1. *Site d'étude.*

water, soil, and Caatinga forest resources. Finally, it presents a pilot participatory governance experiment set up to resolve the identified issues through social organization from the local territory to the state level.

2 Material and methods

2.1 Brief description of study site

This study focused on the Banabuiú watershed region, located in the semi-arid Sertão Central, Ceará, Brazil (Fig. 1), which is a strategic reservoir for Ceará State in critical water storage condition. Its drainage area represents 19,830 km^2, which corresponds to 13.4% of the Ceará State. It comprises 15 municipalities with a population of approximately 450 million (IBGE, 2010). It is characterized by low rainfall (annual average of 600 mm) spread over four months of the year, with high spatial and interannual variability. Crystalline geology limits groundwater storage; there are no permanent rivers and wells are highly susceptible to salinization, making the region highly dependent on rainwater. The native vegetation is a seasonally dry tropical forest that is characteristic of the Caatinga ecosystem. On this watershed, we focus in the municipality of Quixeramobim, the pilot municipality of the

Sertões project, characterized by high climatic vulnerability, a large population, and high stakes on water governance for multiples uses.

2.2 Data and methods

As mentioned in the Introduction, this study is part of a cluster of interdisciplinary action research projects on local water governance and territorial development led by Ceará State (and in particular, the Meteorology and Water Resources Research Institute of Ceará State – Funceme), the French Development Agency, and Cirad (a French research institute). The activities began with a territorial participatory diagnosis of the situation of water governance and territorial development in the Banabuiú watershed region, identifying the main problems and challenges for the region and their systemic nature (Premissa project, 2019–2020). Then, during the Sertões 1 project (2021–2023), different interdisciplinary studies were launched to better document these problems and to fuel the discussion with stakeholders. An ambitious intersectoral participatory process has also begun including multi-level stakeholders from: (i) Ceará State government: secretariat of water resources (SRH), agrarian development (SDA) and environment sectors; (ii) municipal stakeholders from the pilot municipality of Quixeramobim: municipal public authorities, civil society organizations such as Brazilian Landless Workers Movement (MST), rural syndicates, local Non-Governmental Organizations; and (iii) representatives of communitarian associations and family farmers of Quixeramobim and particularly the pilot territory of Forquilha catchment. This participatory process is ongoing in the Sertões 2 project (2024–2026).

Sections 3.1 and 3.2 use the data produced by the different Sertões 1 studies to synthesize the main dynamics around agricultural development and natural resources management and its issues: (i) analysis of publicly available statistical data from Brazilian demographic and agricultural census (IBGE, 2023) and land-use data from Mapbiomas (2023) (Scopel and Freitas Filho, 2022); ii) detailed surveys of the production systems of farmers ($N = 96$) (Alvarenga *et al.*, 2023); and iii) remote-sensing and hydrological modelling (Martins and Vasconcelos, 2022; Martins and Vieira Rocha, 2023).

Section 3.3 presents the intersectoral and multi-level participatory process being experimented to create a shared vision around these issues from the state to the local territory level and to support the stakeholders involved in the co-construction of sustainable territorial trajectories (Tritsch *et al.*, 2023; Tritsch *et al.*, 2024).

3 Results

3.1 Agricultural dynamics in a context of severe drought

3.1.1 The traditional rain-fed shifting agricultural system in association with extensive cattle ranching

Traditionally, the rural livelihoods of family farmers in Sertão have relied on small rain-fed shifting agriculture combined with extensive animal rearing. Most of the production was geared towards self-consumption, and livestock, particularly cattle, was seen as saving capital that could be sold when the family faced any needs. This diversification is the basis of household livelihoods and attempts to best adapt to semi-arid conditions (Burte *et al.*, 2020).

The shifting agriculture system is extensive and involves manual slash-and-burn of the Caatinga forest, followed by several years of cultivation and a fallow period of 7–15 years. During the fallow period, native vegetation grows back, forming a mosaic of forest plots of various ages. This allows the regeneration of soil fertility, and its duration is determined by the farmers' choices, mainly in relation to their own constraints, such as family size and needs, property size, soil quality, and topography. After harvest, during the dry season, livestock feed on crop residues. During the rest of the year, animals are raised in an extensive and loose manner, taking advantage of the fodder potential of the native Caatinga vegetation (Andrieu and Tonneau, 2007). Depending on the severity of the dry season, feeding and watering livestock can be difficult, leading to weight loss, sale of the animals, or even death.

3.1.2 Agricultural intensification and impact of the last multi-year drought

Since 1990, several public development programs have been directed to promote family farming and increase income and production, while limiting the rural exodus. Consequently, family farmers have developed a gradient of intensification, ranging from those with the least natural, social, physical, and financial capital to those who have been able to accumulate a certain amount of capital, providing opportunities for innovation, often supported by more favorable agro-hydro-environmental conditions. Meanwhile, those who have remained in more traditional production systems now depend significantly on non-agricultural activities and income, such as off-farm employment, daily jobs, social programs, and rural retirement pension. For others, two main trajectories of economic intensification have emerged: cattle ranching for dairy production, and small-scale irrigation for fruit and horticulture, with various practices ranging from monoculture to small agroforestry systems (Burte *et al.*, 2020).

The 2012–2018 multi-year drought significantly affected these agricultural trajectories. On one hand, it negatively impacted the dynamics of small-scale irrigation. The irrigated areas in Banabuiú have decreased from 13,000 ha to less than 5000 ha during this period (Fig. 2). This decrease was reinforced by the end of the river perennial process, a practice of releasing water from dams to perpetuate water flow in drainage networks (Burte *et al.*, 2020). On the other hand, the drought has acted as a catalyzer for the dairy intensification trajectory. Although the number of animals slightly decreased (–8%), milk production increased by 79% between 2012 and 2018, despite the drought in these years (Fig. 2). However, these two trajectories may be mixed in the field as multiple activities remain a major characteristic of family farming in the region, providing greater flexibility and adaptation to farms (Ellis, 2000). This is particularly true in alluvial zones, where small-scale irrigation remains important but is increasingly combined with dairy production to supplement income and enhance farm resilience.

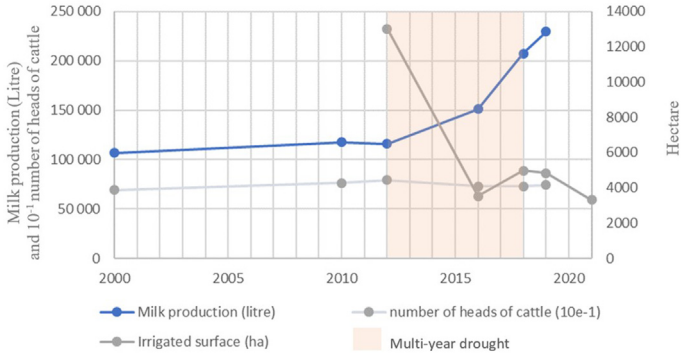

Fig. 2. Evolution of dairy production and irrigated area during drought. Source: Banabuiú watershed irrigated areas from Funceme (2022); Milk production and number of animals in the census mesoregion 'sertão cearense' (including the Banabuiú, Crateus and part of Alto Jaguaribe watersheds) from IBGE (2023).

Fig. 2. *Evolution de la production laitière et des superficies irriguées pendant la sécheresse. Source : Zones irriguées du bassin versant du Banabuiú issues de Funceme (2022); Production laitière et nombre d'animaux dans la mésorégion de recensement 'sertão cearense' (comprenant les bassins versants du Banabuiú, de Crateus et une partie du haut Jaguaribe) issus de l'IBGE (2023).*

3.1.3 The dairy sector making its mark in the region

The increase in milk production during the drought reflects the strong encouragement of the milk sector by most public and private stakeholders. For many stakeholders, including social movements such as the Landless Workers' Movement (MST), the intensification of dairy farming has been seen as an economic opportunity for family farming.

The dairy sector benefits from an important domestic market and attractive prices for farmers (IPECE, 2018), and is seen by most stakeholders as more resilient to drought than irrigated crops. Indeed, it may consume less water at the farm scale than intensively irrigated crops, and during a severe drought event, part of the livestock can be sold or relocated instead of losing the whole production, as with rain-fed crops or even irrigated crops in case of the drying up of the water source.

Therefore, federal, State, and municipal governments have implemented several programs and public policies aimed at developing a dairy production chain, including specialized technical assistance, micro-credit lines, and technological innovations for production intensification, such as livestock genetic improvement or enhancement of feed and pasture management. The private dairy industry has also actively structured its value chains. These actions have improved the productivity, quality, and efficiency gains of the dairy value chain and have resulted in an important increase in milk production in the family farming sector (IPECE, 2018). Indeed, between 2010 and 2019 (during the drought), milk production almost doubled in the Sertão region (in IBGE census mesoregion *'sertão cearense'*), producing more than 200,000 L in 2019, representing almost 30% of the milk production in whole Ceará State (IBGE, 2023).

3.2 Main agricultural transformation and its issues regarding natural resources

3.2.1 Main agricultural practices transformation

This process of development and intensification of the dairy chain has strongly transformed agricultural practices and, consequently, the use of water and forest resources. Most farmers redirect a significant portion of their traditional rain-fed crops towards livestock feed production in more intensive crop systems.

Most producers have begun to produce maize and sorghum silage in mechanized monoculture cropping systems with little rotation and the use of herbicides and pesticides. Some also produce corn grain in more intensive cropping systems (similar to those of silage production) on permanent croplands, although some areas can still be cultivated in the traditional shifting agricultural system (that does not allow mechanization due to tree stumps and roots). The proportion of maize area dedicated to grain production relative to silage was adapted to the climatic conditions of a given year. In drier years, when grain yields are expected to be low, most maize is ensiled rather than lost, an important strategy for small-scale local farmers to adapt to climate risk. Moreover, extensive open grazing areas are increasing, and other crops for livestock feed have emerged, such as cactus palm, a perennial cactus with good drought resistance and interesting nutritional properties for cattle. In addition, some farmers invest in small irrigation systems to irrigate Gramineae areas to increase fodder production. Furthermore, almost all farmers buy animal feed complements, such as triturated soybeans and corn, in addition to phytosanitary products. This option significantly increased the dependence of these family farming systems on external inputs and financialization.

Yet, one of the most important changes is that the production of Gramineae forage has intensified in the lowlands and infiltration areas around dams. These areas benefit from soil humidity and can be cultivated during the dry season, as if it was a 'passive irrigation.' Indeed, crops are planted in water-infiltrating areas as the dam level decreases. With this passive irrigation system, the availability of lowland or infiltration areas around dams becomes an interesting production advantage because, in addition to watering the animals, fodder can be produced in the off-season.

3.2.2 Multiplication of small dams and intensification of cultivation in lowlands

The intensive use of lowlands and infiltration areas around dams for fodder crops had a significant impact on this region.

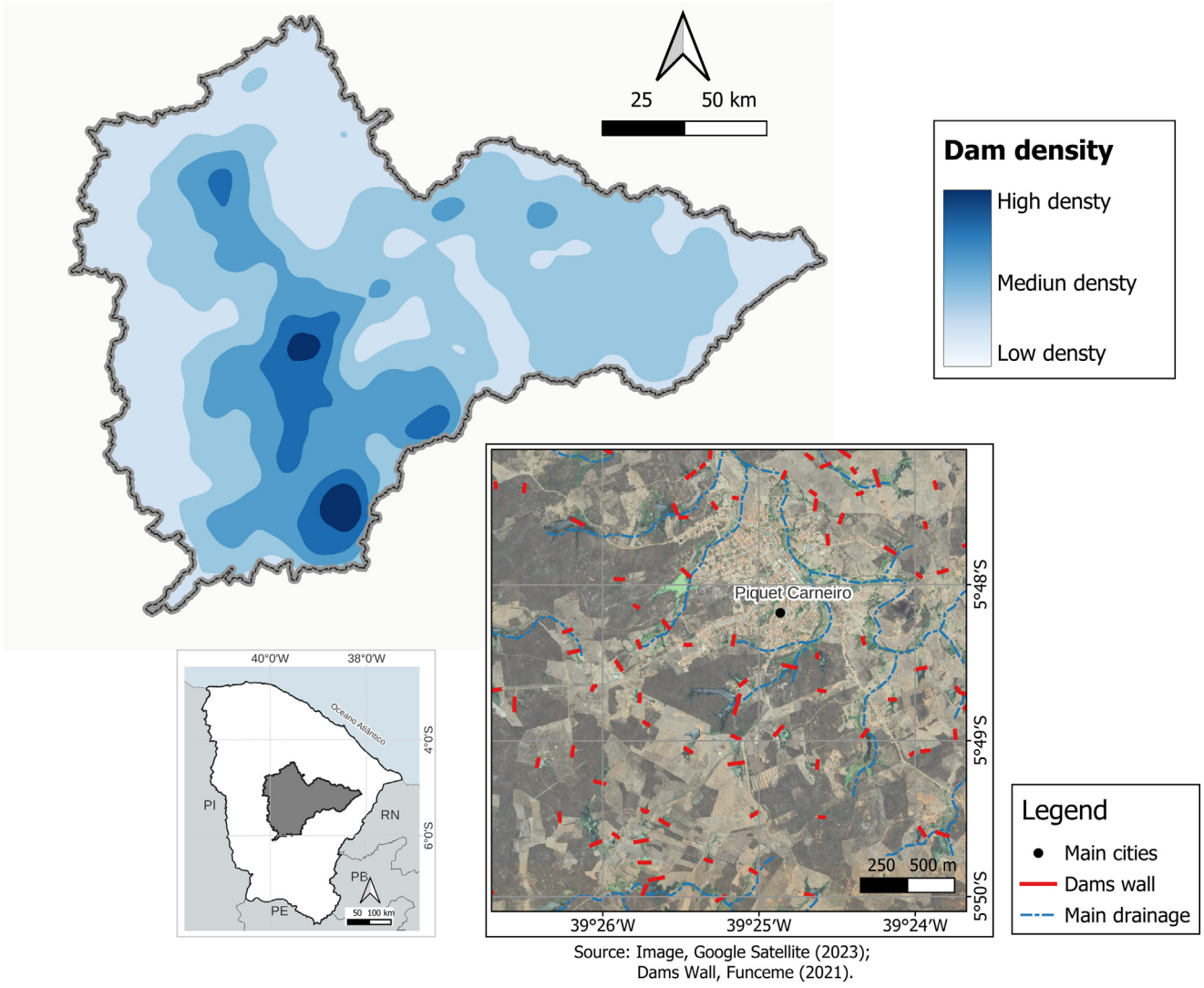

Fig. 3. Dam density in the Banabuiú watershed.
Fig. 3. *Densité de barrages dans le bassin versant du Banabuiú.*

This triggered a strong dynamic in the construction of individual small dams, motivated by individual adaptation strategies in response to water scarcity issues, where people aim for autonomy and independence in their water supply. These small dams have multiple socioeconomic functions, including increasing resilience to drought by diversifying the water source for domestic and productive supply (most producers already having other sources of water for their domestic supply such as rainwater cistern or communitarian wells or reservoirs; Gasmi *et al.*, 2022), enhancing land value, providing water for animal husbandry, and cultivating in water-infiltration areas.

In the Ceará Sertão region, the number of dams currently exceeds 40,000 (Funceme, 2021). Some regions with high specialization in milk production such as Milhã, a Sertão municipality where milk production has increased by more than 700% from 2010 to 2021 (IBGE, 2023), have seen the density of small dams reach more than 5 dams per km^2 (Fig. 3). These small dams are built in a cascade, forming a green continuum: the dam located further upstream releases its water-infiltration planting areas first, followed by the second and so on. Most of these dams having leaks under their wall, they are also planted downstream, creating a continuum of forage crops in the lowlands. Consequently, the 'shallow' dam, although considered inferior in engineering terms by the SRH due to its susceptibility to under seepage and its lower efficiency between storage and evaporation than 'deep' dam, becomes a good model for the farmers as it provides a large planting area throughout the dry season.

The dynamics of planting intensification in lowland areas have various environmental impacts. Suppression of riparian forests leads to greater erosion and silting up (Anbumozhi *et al.*, 2005), affecting water supply and susceptibility to flooding. There is also a tendency for agricultural pollution to

increase owing to the presence of cattle and the increased use of agrochemicals in drainage areas. This contributes to the eutrophication of reservoirs and thus increases evaporation.

3.2.3 Mechanization and impacts on forest regeneration

The intensification of agriculture has significantly altered the relationship between agriculture and the Caatinga forest, principally because of agricultural mechanization in permanent monoculture crops. Mechanization involves permanently clearing land by removing stumps so that the tractor can work without damaging the equipment. This process is not performed in the traditional shifting cropping system, in which planting is done manually between the stumps after slashing and burning the vegetation. Owing to the heavy manual labor required for de-stumping and the scarcity of agricultural labor, there has been a growing trend of using crawler tractors to open new areas of Caatinga by pulling and dumping vegetation and removing roots from the ground. This trend has led to the suppression of forest rotation, as it would be nonsensical to allow the forest to regenerate and then remove the stumps again. In fact, most mechanizable areas have become permanent agricultural lands with no forest rotation. These permanent lands are used for agricultural rain-fed production (grain or silage) or for grazing with native or planted exotic grasses.

However, in return, most of the land unsuitable for mechanization was abandoned for forest regeneration which may leave the balance sheet in terms of the forest surface slightly positive. According to data from Mapbiomas (2023), between 2010 and 2020, the total forest area of the municipality of Quixeramobim increased by 10% (20,787 ha), with a clear decrease in deforestation from the 2010s. These forest gains are mostly situated on slopes and should be interpreted as neglect and devaluation of the forested area (which is no longer useful for regenerating fertility through forest rotations or even for feeding livestock), rather than environmental awareness for natural resource conservation. Nonetheless, this dynamic of mechanization and suppression of forest rotation is also exacerbated by an Environmental State law that complicates the traditional practice of slash-and-burn, requiring an environmental license to burn areas and a context of strong national communications aimed at limiting forest fires and deforestation, such as the Forest Law (12.651/12) (Burte *et al.*, 2020). This contributes to making the Caatinga slash-and-burn unpopular, supporting the process of traditional agriculture abandonment and the shift towards intensive mechanized fire-free systems.

This shift towards intensive mechanized systems raises sustainability concerns regarding soil resources. Yearly mechanized soil tillage with disk arrows, as practiced for silage and grain production, and the opening of mechanized plots in the Caatinga forest with heavy tractors, can be particularly aggressive against soil structure and aggregate stability. The soils of Sertão are particularly fragile and shallow; 94% of the northeast region is classified as vulnerable to desertification (Vieira *et al.*, 2015) and 11.5% of Ceará was considered to be in the process of desertification in 2018 (Funceme, 2018). Without adapted management to control the degradation processes, the erosion and rapid mineralization of soil organic matter can jeopardize production sustainability.

Moreover, changes in the forest and soil management practices may affect the water cycle. The presence of vegetation facilitates the infiltration of water into the soil, thereby promoting the recharge of alluvial aquifers and reducing erosion. However, agricultural practices that are not properly managed can compact the soil and increase surface runoff, thereby exacerbating the effects of drought, desertification, and overall climate change.

3.3 Co-constructing a shared vision on these issues and setting up participatory governance platforms to support collective action

The elements presented in the first two parts of this article were discussed at several intersectoral workshops with SRH, and SDA, and civil society stakeholders. The first one was conducted in the form of a one-week field school in the municipality of Quixerambim, bringing together stakeholders from several State institutions. The aim was to confront them with the reality of the field through workshops and field visits to agricultural properties, dairy cooperatives, and small dams, thus leading them to visualize and discuss the intersectoral impacts of current agricultural dynamics on natural resources (Burte *et al.*, 2020; Tritsch *et al.*, 2023).

The principal point of discussion between the two main State secretaries (SDA – Agriculture, and SRH – Water) and municipal stakeholders is the multiplication of individual small dams in the upstream zone of the large strategic Banabuiú Dam, on which the *Malha d'Água* program depends. The multiplication of these small dams likely impacts the global water dynamics of the region and disturbs the filling of the downstream big reservoirs such as Banabuiú (Martins and Vieira Rocha, 2023), weakening the State's water security. Discussions about agricultural dynamics and farmers' strategies for exploiting lowland and infiltration areas around small dams made it possible to nuance the position of certain stakeholders, who had initially taken a more divisive stance (ex. prohibiting or even destroying individual small dams), as they became aware of their multiple uses and importance for the local economy, particularly for family farmers. A consensus has emerged on the importance of working towards an upstream-downstream trade-off between macro water infrastructures (dams of collective importance for the human supply of rural communities or cities) and micro infrastructures (small individual dams and wells mainly for productive uses). This has introduced the challenge of intersectoral integration because micro-infrastructure dams are part of rural development policy and therefore fall within the remit of the SDA, whereas macro-infrastructure is part of SRH strategies.

To address this challenge, an intersectoral strategy for enhancing territorial governance was co-constructed during the Sertões 1 project. It is based on the multi-level articulation of three participatory governance platforms at the (i) State, (ii) municipal, and (iii) territorial levels. The State level, known as the 'technical committee', mainly comprises engineers from the SRH and SDA system, and in particular from the SDA's Sao José rural micro infrastructure program. Two of its objectives are to plan the main investments of the two secretariats in a more coherent manner and to encourage

public policies for an agroecological transition that consumes less water and supports the better use of lowland areas. At the municipal level, a pilot 'municipal water council' (*conselho municipal da água*, CMA) is being set up to involve in the participatory process the municipal agriculture and environment secretary and local civil society organizations. One of its objectives is to initiate a local debate on trajectories of agroecological transition, territorial planification and sustainable use of water for agriculture (for more information on the other objectives of the CMA and the Sertões pilot model for multi-level territorial water governance, see: Tritsch *et al.*, 2023).

Finally, at the territorial level, the activities were concentrated in a pilot micro catchment territory (Forquilha catchment, Quixeramobim), a territory selected by municipal stakeholders because of its important rural population (24 rural communities), strong community organization, and significant agricultural potential. A participatory territorial diagnosis was conducted to identify the main issues surrounding the management of the territory's natural resources and the various challenges perceived by the inhabitants (Alves *et al.*, 2024; Tritsch *et al.*, 2024). Three major controversies emerged in line with the elements presented in Section 3.2: (i) the use of "agrotoxics" (pesticides) and the increasing pollution of the water, (ii) the management of the communitarian dam located upstream in the valley, and (iii) the removal of the riparian forest and the grassing of the main river in the valley due to cattle farming, which amplifies flooding vulnerability during heavy rains. A territorial committee bringing together representatives from upstream and downstream communities was established to discuss territorial planification and, more specifically, these three issues. Different participatory methodologies (such as a serious game to highlight the interactions between water resources and agriculture and the interrelation between upstream and downstream areas) were used to support participants in the search for solutions and trade-offs for these three challenges (Tritsch *et al.*, 2023). This multi-level participatory experiment is ongoing.

4 Conclusion

The multi-year drought from 2012 to 2018 had a significant impact on the agricultural sector in the Sertão region. Associated with strong public policies and support from the public and private sectors, the region has experienced a strong dynamic of dairy intensification, resulting in the intensification of rain-fed agriculture and fodder production in the lowlands, as well as a strong dynamic in the construction of small individual dams for fodder production.

The multiplication of these small dams in the areas upstream of large strategic dams for human water supply, disturbing their filling, has emphasized the necessity of territorial planification. It is particularly important to find an upstream-downstream trade-off between macro water infrastructure (dams of collective importance for the human supply of rural communities or cities) and micro infrastructure (small individual dams and wells mainly for productive uses), supported by the water and agrarian sectors (*i.e.*, the SRH and SDA). After the creation of a shared vision about these dynamics between stakeholders in the water and agriculture sectors (traditionally accustomed to working in silos), a multi-level territorial governance experiment was conducted to break down the barriers between the stakeholders and support them in the search for intersectoral and territorial solutions to be implemented to optimize water management while promoting sustainable agricultural development. Three intersectoral participatory governance platforms articulated together from the state to the territorial level are being tested in an attempt to decompartmentalize public action targeting rural territories and promote a more bottom-up approach to territorial development. This involves supporting stakeholders in territorial planning, the search for trade-offs in the management of the natural resources of their territory, and the co-construction of agroecological territorial trajectories. These initiatives started in phase 1 of the Sertões project (2021–2023) and will be continued in phase 2 (2024–2026). This presents important challenges in terms of strengthening the skills of stakeholders and establishing multi-stakeholder cooperation processes.

Acknowledgments

This work was funded by the French Development Agency (AFD) through the projects Sertões 1 (Facilités 2050) et Sertões 2 (Fexte) and the Capes-Cofecub (Grant number: 88881.711964/2022-01).

References

Alvarenga I, Tritsch I, Scopel E. 2023. Trajetória da resiliência Agrícola em uma perspective de baixo carbono e de transição agroecológica. Relatório do produto 8, Projeto Sertões. Funceme-Cirad, Fortaleza, Brasil, 48 p.

Alves R, Fontenele D, Dehon J, Thais Souza S, Nascimento Diniz R, Tritsch I, *et al.* 2024. Aplicação de processamento de linguagem natural nos dados de um diagnóstico rural participativo. Anais do XVII Simpósio de Recursos Hídricos do Nordeste, 24 a 29 novembro de 2024, João Pessoa, Brasil, 10 p. https://anais.abrhidro.org.br/job.php?Job=16786.

Anbumozhi V, Radhakrishnan J, Yamaji E. 2005. Impact of riparian buffer zones on water quality and associated management considerations. *Ecolog Eng* 24: 517–523.

Andrieu N, Tonneau JP. 2007. Gestion agroécologique de la caatinga pour les agriculteurs familiaux du *Sertão* : une alternative à sa désertification? *Bois et Forêts des Tropiques* 293: 9–21.

Burte J, Martins ES, Augusseau X, Garjulli R. 2020. Resiliência e desenvolvimento sustentável rural na região Banabuiú/Médio Jaguaribe. Diagnóstico Territorial e dos sistemas de Governança e de Informação. Funceme-Cirad, Fortaleza, Brasil, 148 p. https://agritrop.cirad.fr/597085/.

Cavalcante L, Dewulf A, van Oel P. 2022. Fighting against, and coping with, drought in Brazil: two policy paradigms intertwined. *Regl Environ Change* 22: 111.

Ellis F. 2000. Rural livelihoods and diversity in developing countries. Oxford University Press.

Funceme. 2018. Dia Mundial de Combate à Desertificação: ações e conscientização humana para um futuro sustentável. [07/02/2023] http://www.funceme.br/?p=1739

Funceme. 2021. Mapeamento das barragens dos pequenos reservatórios d'agua situados no Estado do Ceara. Relatório Técnico interno. Fortaleza, Brasil. 10 p.

Funceme. 2022. Áreas Irrigadas em 2022 na bacia hidrográfica do Rio Jaguaribe-*CE*. Relatório Técnico interno. Fortaleza, Brasil. 11 p.

Gasmi H, Kuper M, Martins ES, Morardet S, Burte J. 2022. Sustaining community-managed rural water supply systems in severe water-scarce areas in Brazil and Tunisia. *Cahiers Agricultures* 31: 21.

IBGE. 2010. Censo demográfico 2010. [05/02/2023] https://censo2010.ibge.gov.br/

IBGE. 2017. Censo agropecuário 2017. [05/02/2023] https://censoagro2017.ibge.gov.br/

IBGE. 2023. Pesquisa da pecuária Municipal [05/02/2023] https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9107-producao-da-pecuaria-municipal.html?=&t=series-historicas

IPECE. 2018. Analise da cadeia produtiva do leite e seus derivados no Ceara. IPECE Informe n° 128 Fortaleza (Brasil): Ipece, 27 p. https://www.ipece.ce.gov.br/wp-content/uploads/sites/45/2018/09/ipece_informe_128_30_Maio_2018.pdf.

Mapbiomas. 2023. Coleção 7.0 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil, [05/02/2023]. https://mapbiomas.org/

Martins E, Magalhães AR. 2017. A seca plurianual de 2010-2017 no Nordeste e seus impactos. Parcerias Estratégicas (Impresso), v. 22, pp. 17–40. http://seer.cgee.org.br/index.php/parcerias_estrategicas/article/viewFile/844/772.

Martins ES, Vasconcelos FJ. 2022. Análise dos impactos das secas e da variação hidroclimática sobre a resiliência hídrica na bacia do Banabuiú. Relatório do produto 1, Projeto Sertões. Funceme-Cirad, Fortaleza, Brasil, 40 p.

Martins ES, Vieira Rocha R. 2023. Modelagem hidrológica – importância, iniciáticas atuais e desafios. Relatório do produto 13, Projeto Sertões. Funceme-Cirad, Fortaleza, Brasil, 39 p.

Pontes Filho JD, Souza Filho FA, Martins ES., Studart TMDC. 2020. Copula-based multivariate frequency analysis of the 2012–2018 drought in Northeast Brazil. *Water* 12: 834.

Scopel E, Freitas Filho MR, 2022. Dinâmica das trajetórias agrícolas na bacia do Banabuiú. Relatório do produto 2, Projeto Sertões. Funceme-Cirad, Fortaleza, Brasil, 40 p.

Souza Filho FA 2018. Ceará 2050: Estudo Setorial Especial – Recursos Hídricos. Fortaleza, Brasil, 94 p. https://www.ceara2050.ce.gov.br/api/wp-content/uploads/2018/10/ceara-2050-estudo-setorial-especial-recursos-hidricos.pdf.

Tritsch I, Garjulli Sales Costa R, Vieira Rocha R, Martins ES. 2023. Co-construção de um Modelo de Governança Territorial da Água. Relatório do produto 12, Projeto Sertões. Funceme-Cirad, Fortaleza, Brasil, 46 p. https://doi.org/10.18167/agritrop/20310

Tritsch I, Scopel E, Martins ES, Benicio M, Sakamoto M, Vieira Rocha R. 2024. Processo de co-construção e resultados do diagnostico territorial piloto realizado na bacia do Forquilha. Relatório do Projeto Sertões. Funceme-Cirad, Fortaleza, Brasil, 42 p.

Vieira RDSP, Tomasella J, Alvalá RCS, Sestini MF, Affonso AG, Rodriguez AA, *et al.* 2015. Identifying areas susceptible to desertification in the Brazilian northeast. *Solid Earth* 6 (1): 347–360.

Cite this article as: Tritsch I, Scopel E, Alves RdS, Nascimento Diniz RS, Linhares SS, Filho JDdAP, Fontenele DP, Júnior FdCV, Mitroi V, Burte J, Augusseau X, Martins ESPR. 2025. Agricultural dynamics in the semi-arid Northeast region of Brazil: issues for natural resources management and territorial governance. *Cah. Agric.* 34: 14. https://doi.org/10.1051/cagri/2025012.