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INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

Perceived impacts on ecosystem services and coping strategies by dairy farmers in the Atlantic Forest of Rio de Janeiro during the drought of 2014-2017

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

DEGREE AWARDED BY UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ

AND

MASTER OF SCIENCE

NATURAL RESOURCES MANAGEMENT AND DEVELOPMENT

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COLOGNE, GERMANY 11.08.2019

Universidad Autónoma de San Luis Potosí
Facultades De Ciencias Químicas, Ingeniería, Medicina
y Ciencias Sociales y Humanidades
Programa Multidisciplinario De Posgrado En Ciencias Ambientales
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Institute for Technology and Resources Management in the Tropics and Subtropics

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ABSTRACT

Soils are complex, evolving systems that simultaneously shape and are shaped by numerous biotic and abiotic factors in a vast web of interactions that creates the conditions for the propagation of life and the maintenance of human societies. Yet, land use and land use change (LULUC) and anthropogenic climate change (CC) are forcing substantial and rapid alterations into soil's properties and processes, thus affecting the functions and services derived from it. The resulting land degradation (LD) is now spread, according to recent estimates, over nearly 30 % of the world's total land, mostly on the population dense and impoverished tropics, a zone predicted to withstand the worst impacts of CC. The Atlantic Forest in Brazil is a particularly vulnerable environment, and the unusual drought of 2014-2017 that hit its Southeastern region is likely the harbinger of a progressively drier future.

The way the prelude of what might be an increasingly frequent hazard affected farmers' livelihoods and natural resources, and the manner in which they reacted to those impacts can thus reveal points of strength and fragility that could be respectively harnessed or addressed to develop a more sustainable agriculture and climate resilience. This master thesis focused on characterizing those impacts and reactions on distinct dairy production systems in two municipalities in Northwestern Rio de Janeiro: Santo Antônio de Pádua and Cambuci. Through interviews and *in loci* observations, the researcher collected data concerning environmental services (erosion prevention, soil cover and water provision), production variables (inputs and outputs), socio-economic information, farm system management and farmers' future perspectives. The results show that dairy production systems in the region are heterogeneous and, although they may share common characteristics, drought outcomes were closely tied to the specificities of each farm. Ultimately, outcomes originated from differences in water supply, water demand, and feed availability, their subsequent change by the drought and farmers' reaction to those changes at each property.

Keywords: drought impacts; land degradation; coping strategies; ecosystem services; dairy systems

RESUMEN

Los suelos son sistemas complejos y en evolución que simultáneamente forman y están formados por numerosos factores bióticos y abióticos en una vasta red de interacciones que crean las condiciones para la propagación de la vida y el mantenimiento de las sociedades humanas. Sin embargo, el uso de la tierra y el cambio de uso de la tierra (LULUC) y el cambio climático antropogénico (CC) están forzando alteraciones sustanciales y rápidas en las propiedades y procesos del suelo, lo que afecta las funciones y los servicios derivados de él. La degradación del suelo resultante (LD) ahora se extiende, según estimaciones recientes, por casi el 30% de la superficie terrestre, principalmente en los trópicos, dónde se concentra la población y la pobreza del mundo, una zona prevista a resistir los peores impactos del CC. El Bosque Atlántico en Brasil es un entorno particularmente vulnerable, y la inusual sequía de 2014-2017 que azotó su región sureste es probablemente el presagio de un futuro progresivamente más seco.

La forma en que el preludio de un peligro quizás cada vez más frecuente afectó los medios de vida y los recursos naturales de los agricultores, y la manera como reaccionaron a esos impactos pueden revelar fortalezas y fragilidades que podrían aprovecharse o abordarse para desarrollar una agricultura más sostenible y resiliencia climática. Esta tesis de maestría se enfocó en caracterizar esos impactos y reacciones en distintos sistemas de producción de lácteos en dos municipios del noroeste de Río de Janeiro: Santo Antônio de Pádua y Cambuci. A través de entrevistas y observaciones *in loci*, el investigador recopiló datos sobre servicios ecosistémicos (prevención de la erosión, cobertura del suelo y suministro de agua), variables de producción (entradas y salidas), información socioeconómica, gestión de los sistemas agrícolas y perspectivas futuras de los agricultores. Los resultados muestran que los sistemas de producción de lácteos en la región son heterogéneos y, aunque pueden compartir características comunes, las consecuencias de la sequía estuvieron estrechamente vinculadas a las especificidades de cada finca. En última instancia, ellas se originaron en las diferencias en el suministro de agua, en la demanda de agua y en la disponibilidad de pienso, el posterior cambio que esos tres factores sufrieron durante la sequía y la reacción de los agricultores ante esos cambios en cada propiedad.

Palabras clave: impacto de la sequía; degradación del suelo; estrategias de afrontamiento; servicios ecosistémicos; sistemas lácteos

1 INTRODUCTION

Soil is of paramount importance to living beings. For plants, it provides nutrients, substrate for growth, shelter for seeds and a medium through which water can be stored and accessed. For animals, it provides food, shelter and the means of locomotion. In a bigger scale, soils interact with biogeochemical cycles in a myriad of ways, and the results of those interactions—e.g. nutrient and water storage, filtering and transformation, carbon storage and sequestration, biomass production, flood regulation, and waste recycling, amongst others—create the conditions for the maintenance of most life on Earth.

Those direct and indirect benefits living beings derive from soil and its interactions, or *functions* (Blum, 1988 *as cited in* Baveye, Baveye, & Gowdy, 2016), can expand considerably once human needs are considered. In that regard, soils do not only provide food, but also raw materials for a multitude of finalities. They become the substrate on which residences, villages, roads, farms and industries are built. They also gain personal, cultural and religious significances that transcend their materiality; hence, the soil onto which one is born, *jus soli*, the sacred earth, burial grounds, *terri*tory, the salt of the earth, and so on. Thus, it is possible to say that the soil provides goods and services to human societies, which are functions seen through anthropomorphic lens and connected to our specific needs (de Groot, Wilson, & Boumans, 2002).

In the opposite direction, human activities directly or indirectly impose disturbances on soils that have the potential to alter how well it provides goods and services. Land use management, land use and land use intensity changes can contribute directly to a change in soil properties (FAO and ITPS, 2015). When that alteration subtracts from the ability of the soil to provide further services, the process is called land or soil degradation.

Land degradation, identified as “the single most pressing current global problem” (O’Riordan, 2000 *as cited in* M. A. Stocking, 2001), is an old problem in new clothes. Correlate terms e.g. soil salinization, soil loss, desertification, and waterlogging have long history of association with the decline of both modern and ancient civilizations (Safriel, 2007). The theme gained considerable traction at the international level during the late 1980’s and through the 1990’s, starting with the publication of the Brundtland Report (1987), which highlighted it as a challenge to sustainable agriculture, and reaching a fevered pitch with the ratification of the

United Nations Convention to Combat Desertificatio*n* in 1998, when it (M. A. Stocking, 2001). The latest convention also provided according to Safriel (2007, p. 2) an "international legally-binding definition", later updated with the publication of the Millennium Ecosystem Assessment (2005).

Estimates for land degradation vary according to the terminology and the definition used (Zorn & Komac, 2013). The most comprehensive effort so far to paint a global picture of problem was published in 1991 as the Global Assessment of Soil Degradation (GLASOD), a project sponsored by the United Nations Environment Programme (UNEP) with the objective to identify soil degradation at a global scale (Bouma & Batjes, 2000; Safriel, 2007). According to the report, close to 15% of the world's total land area is degraded, with the main types being water (56%) and wind (38%) erosion, caused mostly be deforestation, overgrazing, improper agricultural land management, overexploitation of vegetation cover and chemical pollution from industrial activities (Oldeman, Hakkeling, & Sonbroek, 1991). More recent studies show a bleaker picture, with 24% (Bai, Dent, Olsson, & Schaepman, 2008) to 29% (Le, Nkonya, & Mirzabaev, 2016) of global total land area showing signs of degradation at some point in the last 40 years, indicating towards accelerated rates of land degradation.

Land degradation has significant social and economic costs, multiplied by the level of severity. By reducing the productivity of arable land, it saps countries' wealth growth and economic development potential, compromising food security and increasing the risk of conflicts (Zorn & Komac, 2013). In monetary terms, a rough calculation puts yearly losses of land degradation in terms of ecosystem services at around US$231 billion in 2007 values due to land use and land cover change (LUCC) alone (Nkonya *et al*., 2015). The cost is particularly severe for developing and least developed countries, with Sub-Saharan Africa and Latin America accounting for nearly half of those losses.

The costs of land degradation are likely to rise with climate change. Soil moisture droughts will become increasingly common in transition areas between wet and dry climates, such as in southern Europe, with dire consequences to agricultural crops during hotter months (Cheng & Huang, 2016; Samaniego *et al*., 2018). Greater aridity will also result in the expansion of the drylands, currently home to 38% of humanity, substantially decreasing the percentage of available cropland and putting enormous pressure on burgeoning global population (Huang, Yu, Guan, Wang, & Guo, 2016). Greater variability in rainfall patterns and biomass production, which impede the establishment of vegetation cover and improves the chances of concentrated rainfall events, will further strain those regions resources by enhancing vulnerability to erosional processes (Gisladottir & Stocking, 2005).

There is no doubt agriculture is a driver of land degradation and climate change through LUCC, biodiversity loss and intensive livestock farming (FAO and ITPS, 2015). Yet, covering 38% of the world's land surface, it is also the most exposed system to environmental hazards and the main consumer of an array of environmental services that it is helping to destroy (Foley *et al.*, 2011). Agriculture in the tropics is particularly vulnerable, as it will withstand the worst of increased global aridity, accelerated soil loss and shrinking productivity, thus negatively affecting the livelihoods of farmers in already impoverished region (Lal, 1990). In that scenario, smallholders in transition zones between wet and dry climates already experiencing the first signs of climate change are a group of special interest to mitigation and sustainability efforts. They provide a unique of opportunity for intervention and learning experiences, both of which critical to establish a systematic, large scale approaches to radically move agricultural practices the world over towards sustainability and climate resilience.

However, farming systems are highly heterogeneous and practices vary considerably in space and time, often shaped by culture and local environmental conditions. Thus, before any intervention, local systems should be studied and their impact on environmental services described and characterized in order to tailor the approach to the particulars of that region. For the case of Rio de Janeiro (RJ), Brazil, a state whose countryside is currently occupied by degraded pasture areas (Hebner *et al.*, 2018; Sattler *et al.*, 2018; Seliger, Sattler, Soares da Silva, da Costa, & Heinrich, 2019), there is a dearth of studies characterizing livestock raising practices and their individual impact on ecosystem services. Similarly, the effects of the latest drought (2014-2017), one of the few ever to hit the region (Nehren, Kirchner, Lange, Follador, & Anhuf, 2018), on the social-ecological systems of cattle ranching remain largely unstudied.

The work of Mergner (2018) was the first step in addressing that research gap. By surveying farmers' perceptions and attitudes regarding the impacts of climate change on their livelihoods in two municipalities in Rio's Northwest region, the author managed to give an overview of the pressures upon them and their responses to it. However, no attempt was made to identify different production systems and their relationship with the drought outcomes observed by each farmer.

The current study thus attempts to perform an in-depth characterization of the dairy production systems in the municipality of Santo Antônio de Pádua and their relation with the socio-economic and ecological impacts of the 2014-2017 drought.

2 OBJECTIVES

2.1 GENERAL OBJECTIVE

To characterize the socio-economic and ecological impacts of the drought of 2014-2017 on dairy agroecosystems in the Atlantic Forest of Rio de Janeiro, Brazil.

2.2 SPECIFIC OBJECTIVES

i. To describe changes in the provisioning of ecosystem services during the drought period in dairy farms;
ii. To describe the effects of the drought on social-economic and productive variables in dairy farms;
iii. To identify the coping strategies adopted by dairy farmers to face the drought.

3 THEORETICAL FRAMEWORK

3.1 ECOSYSTEM SERVICES

Although the concept ecosystem services (ES) is relatively new, with its first use documented in 1981 by Ehrlich and Ehrlich (Chaudhary, McGregor, Houston, & Chettri, 2015), the idea of valuing nature's services dates back to the 1940s in an attempt to bring conservationism into the attention of decision-makers and financiers (Baveye *et al*., 2016). In the 1960s and the 1970s the number of works concerning "ecosystem functions", environmental goods and services" or "environmental amenities" ballooned, just to die down in the following two decades, and later resurrect in the late 1990s with the seminal writings of Costanza *et al*. (1997) and Daily (1997).

At that time, divergences existed on the very definition of what were ecosystem services, which some defined as "benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza *et al*., 1997), while others preferred "conditions and processes associated with natural ecosystems that confer some benefits to humanity" (Daily, 1997). Such divergence was put to relative rest when the term was defined by the Millennium Ecosystem Assessment (2005) as the "benefits people obtain from ecosystems".

If the MA pacified the contentious issue of definition, it failed to reach a peaceful compromise on the classification of such services. The initially proposed classification had four broad categories: supporting services, provisioning services, regulating services and cultural services. A revision by the international committee "The Economics of Ecosystems and Biodiversity" (TEEB) removed the "supporting services", adding "habitat services" and "ecosystem functions" in its place (Baveye *et al*., 2016). More recently, the European Environmental Agency (EEA) launched its own classification system, the Common Classification of Ecosystem Services (CICES). In the latest version of CICES (5.1), there are only three main categories: provisioning, regulation and maintenance, and cultural (Haines-Young & Potschin, 2018).

Regardless of such changes, the little attention given to soils in the original MA classification scheme remains in its institutionalized modern relatives. Indeed, it has been argued (Adhikari & Hartemink, 2016; Baveye *et al*., 2016; E. Dominati, Patterson, & Mackay, 2010; Prado *et al*., 2016) that soils have been undervalued in the ecosystem services frameworks (ESF). A number of soil specific ecosystem frameworks (Daily, 1997; E. Dominati *et al*., 2010; Weber, 2007) attempt to fill that gap, but according to Jónsson & Davídsdóttir (2016, p. 27), they are still incomplete. Indeed, the same authors argue that a successful framework should include "1) the connection between soil natural capital, soil functions and soil ES; 2) categorization of the different services; 3) the potential beneficiaries of the soil ES; and 4) how to value economically the benefits".

Perhaps the most influential of the proposed frameworks so far is the one presented by Dominati *et al*. (2010). Based on stocks and flows, the authors attempted a holistic linkage between stocks of soil natural capital and flows of ecosystem services emerging from it. Therefore, processes that form, maintain, and degrade those stocks of natural assets, which arise from natural and anthropogenic drivers, will affect the provision of goods and services offered by the soil, and ultimately, their availability to human needs.

Baveye *et al*. (2016) illustrative framework builds upon Dominati *et al*.'s (2010) proposition, but takes on a new approach to the distribution of stocks and flows and the interactions between them (Figure 1). Here, the authors fully incorporate soil processes and properties into soil natural capital, as their inextricably dynamic interactions are an integral part of soil richness. There is also no division between inherent and manageable soil properties, as human beings are at least theoretically capable of affecting every single one of them. Additionally, ecosystem services are seen as a subset of natural functions, which more broadly includes services provided to every living being. Ecosystem services are not seen as a unidirectional flow into human needs, but as a bidirectional relationship in which humans select which functions are services. Similarly, human populations also establish the kind of relationship they want to have with soil natural capital, altering its evolution.

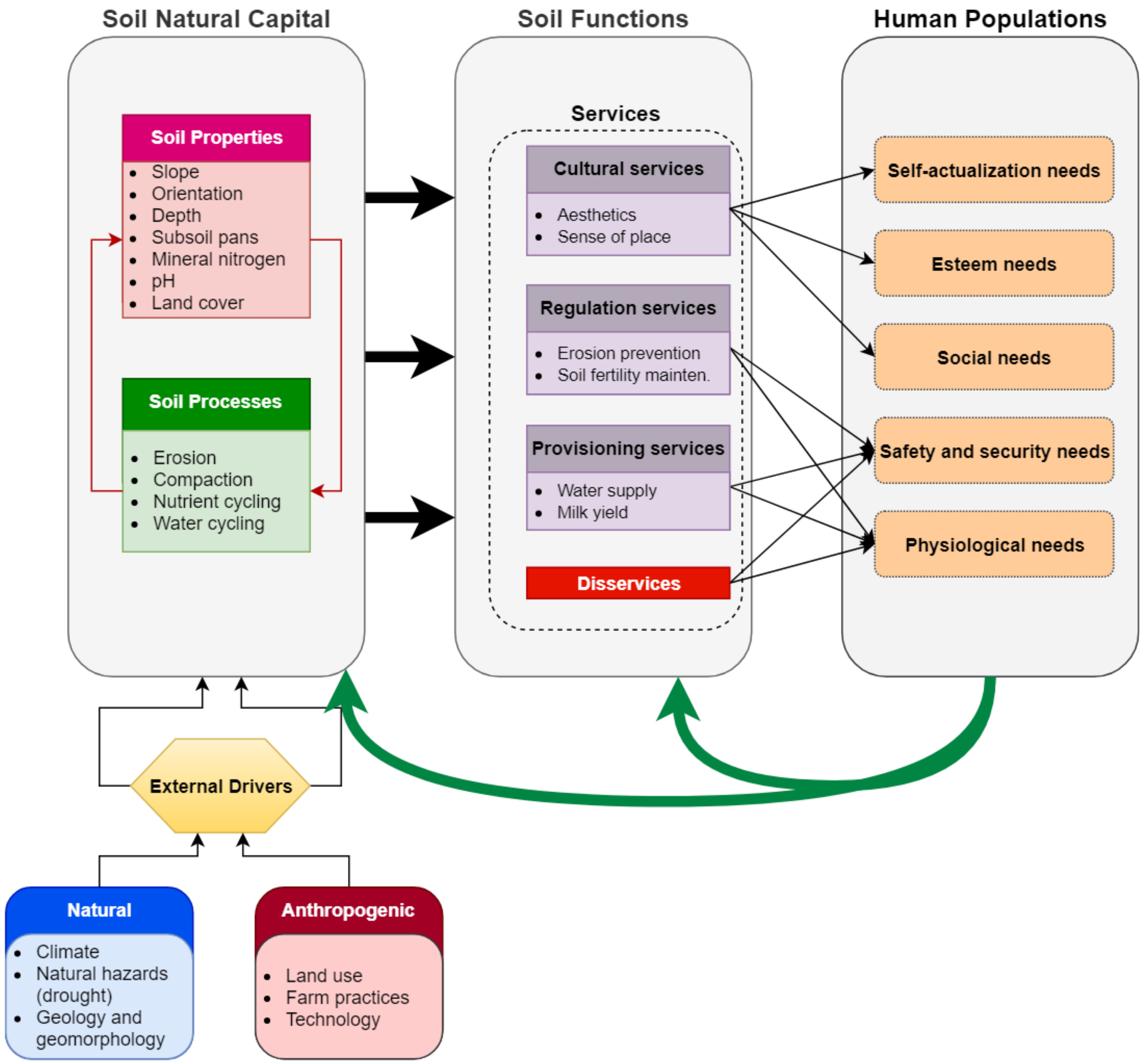

Figure 1 – Schematic diagram showing the relationships between soil natural capital (comprised of interrelated properties and processes and affected by external drivers that can be natural or anthropogenic), soil functions (of which services and disservices are a subgroup) and human population (consisting of a variety of needs fulfilled by specific services). Adapted from Baveye et al. (2016).

3.1.1 Agriculture and ecosystem services

Agriculture occupies nearly one-quarter of the land on Earth (Millennium Ecosystem Assessment, 2005), composing thus one of the largest ecosystems on the planet. It represents the imposition of human priorities on natural areas, transforming forests and grasslands into croplands and pastures with the goal of producing fiber, food or fuel. However, by being in the position of a managed production system, agriculture unintentionally provides and receives other ecosystem services and disservices (Swinton, Lupi, Robertson, & Hamilton, 2007).

That peculiarity led to the development of special ecosystem services frameworks focused on agroecosystems. Within those, numerous regulating and supporting services have been identified, the most common of which are summarized and compared between different authors in **Table 1**. Those services are required by agriculture to perform its production goals, and are related to plant environment and nutrition, water needs, herbivory and climate.

Table 1 – Ecosystem services required by agroecosystem identified by different authors

Zhang *et al*. (2007)	Sandhu *et al*. (2008)	Power (2010)
Pest control	Biological control of pests	Pest control
Pollination	Pollination	Pollination
Soil fertility and formation, nutrient cycling	Soil fertility	Soil conservation, structure and fertility
	Nitrogen fixation	
	Mineralization of plant nutrients	
Soil retention	Soil formation	Nutrient re/cycling
Water provision and purification	Hydrological flow	Water provision, quality and quantity
Climate regulation	Carbon accumulation	Carbon sequestration
Genetic diversity		Biodiversity

Table 1 shows an agreement between different authors concerning certain categories of services and a significant confusion when it relates to others. The classification of soil-related ecosystem services seems to suffer the most, with divergences on what is considered an independent service and what is not. The interdependence of soil processes and properties, as seen in the previous section, make for a particularly difficult desegregation between them and individual services. It can be argued, for instance, that mineralization of plant nutrients is a process rather than a service and it is subjacent to soil fertility. The same can be said of nutrient cycling and nitrogen fixation. Therefore, for quantification of ES, it is advisable to define and separate individual services with rigor, lest they will be counted more than once (E. J. Dominati, Mackay, Bouma, & Green, 2016).

For the purposes of this thesis work, three concepts will then be defined and contextualized*: water supply*, *soil fertility*, and *or erosion prevention*. The first is often described as a function of soil infiltration, flow and soil moisture retention, and it is quality and quantity is directly related to the vegetation cover (Power, 2010; Zhang *et al*., 2007), although by no means the only factor governing it. The second, soil fertility is "the quality of a soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specified plants" (Weil & Brady, 2017; p. 1076). Fertility is associated with soil structure, organic matter and the nutrients available for plant sustenance (Zhang *et al*., 2007). Lastly, erosion prevention is closely associated to soil fertility and can be understood as the soil property of maintaining its integrity and retaining nutrients for the plants. Preservation, similarly to water provision, also privileges from vegetation cover, which helps to reduce erosion and runoff (Zhang *et al*., 2007).

3.1.2 Land, soil and pasture degradation

Land degradation can be defined in multiple ways. In simple terms, it is a *"*natural or human-induced process that negatively affects the land to function effectively within an environmental system (Zorn & Komac, 2013; p. 580)," implying thus change from a state of functionality to a state of dysfunctionality. Land there is seen as part of a larger system, filling a role in a number of processes engaged by its components. While such a broad definition might be useful to understand the impact of degradation on those processes, it is not very practical when applied to socioecological systems. A narrower way to define land degradation would then be *"*[the] loss of a sustained economic, cultural, or ecological function due to human activity in combination with natural processes (Bush, 2006 *as cited in* Zorn & Komac, 2013, p. 580)."

That second definition has several advantages, including, for instance, the emphasis of human-related causes over natural ones, recognizing then the disproportional impact of humankind on Earth, to the point of scientists calling the current geological age the "Anthropocene" (Crutzen, 2006). The greatest advantage is, however, for analytical purposes, the approximation to the concept of ecosystem services. If services were substituted for function, it follows that land degradation would signify then a loss in the provisioning of ecosystem services. Indeed, this linkage was already acknowledged by the Millennium

Ecosystem Assessment (2005) and its usage is widespread, especially within the field of total economic valuation of ES (ELD-Initiative, Thomas, Quillérou, & Stewart, 2013; Turner *et al*., 2016).

It is important to distinguish land degradation from soil degradation, although in the literature sometimes both terms are used interchangeably. The former has a much broader focus, encompassing not only the latter, but also "natural resources, such as climate, water, landforms and vegetation" (Stocking & Murnaghan, 2001, p. 7). However, in practice, soil degradation is the main, if not the only indicator, used to evaluate land degradation. Therefore, soil indicators such as erosion, fertility decline, salinization and waterlogging are usually taken as proxies for land degradation (M. Stocking & Murnaghan, 2001).

Pasture degradation is to land degradation what *pasture* is to land use, that is, a particular subset. Consequently, pasture degradation can be similarly defined as a progressive deterioration in the supply and demand of ecosystem services by pasturelands. However, such definition creates a few practical problems, the greatest of which arising from the subjective and contextual nature of ecosystem services, leading to the questions of what services should be indicators of degradation and how they should be weighed against each other. The same issues occur in the fields of land and soil degradation, which has led to a considerable multiplicity of approaches, often tailored to the methodology, to identify and quantify degradation.

In the particular case of pasture degradation, remote sensing studies often use vegetation cover, height and vigor as the main indicators (Calegario *et al*., 2019; Naegeli de Torres, Richter, & Vohland, 2019), while field studies would rely mainly on visual assessment of vegetation cover (Rocha Junior, Donagemma, *et al*., 2017; Rocha Junior *et al*., 2014). Those indicators would then be validated *ex post facto* by comparing soil properties and processes between preserved and unpreserved patches of land (Rocha Junior, Donagemma, *et al*., 2017).

3.2 Drought

Wilhite & Buchanan-Smith (2005) define drought as "an insidious natural hazard that results from a deficiency of precipitation from expected or "normal" that, when extended over a season or longer, is insufficient to meet the demands of human activities and the environment." From that definition, it is possible to draw three conclusions. The first, is that drought is a slow-onset natural hazard, sometimes described as a "creeping phenomenon", for its effects tend to grow little by little over a long period. Second, because expected precipitation depends on the climate regime and its characteristics and human demands vary considerably for countless reasons, drought is relative; therefore, its definitions will reflect the context of its creation, which is one of the reasons for the absence of a universally accepted definition that is not broad in scope. Lastly, drought impacts are "nonstructural", that is, they do not manifest themselves as infrastructural or "visible" damage, and its effects may be felt in a very large area. That coupled with its insidious nature makes detection and quantification of impacts difficult.

The National Drought Mitigation Center (NDMC) of the University of Nebraska [1] divides drought in four main types, as exemplified in the following figure:

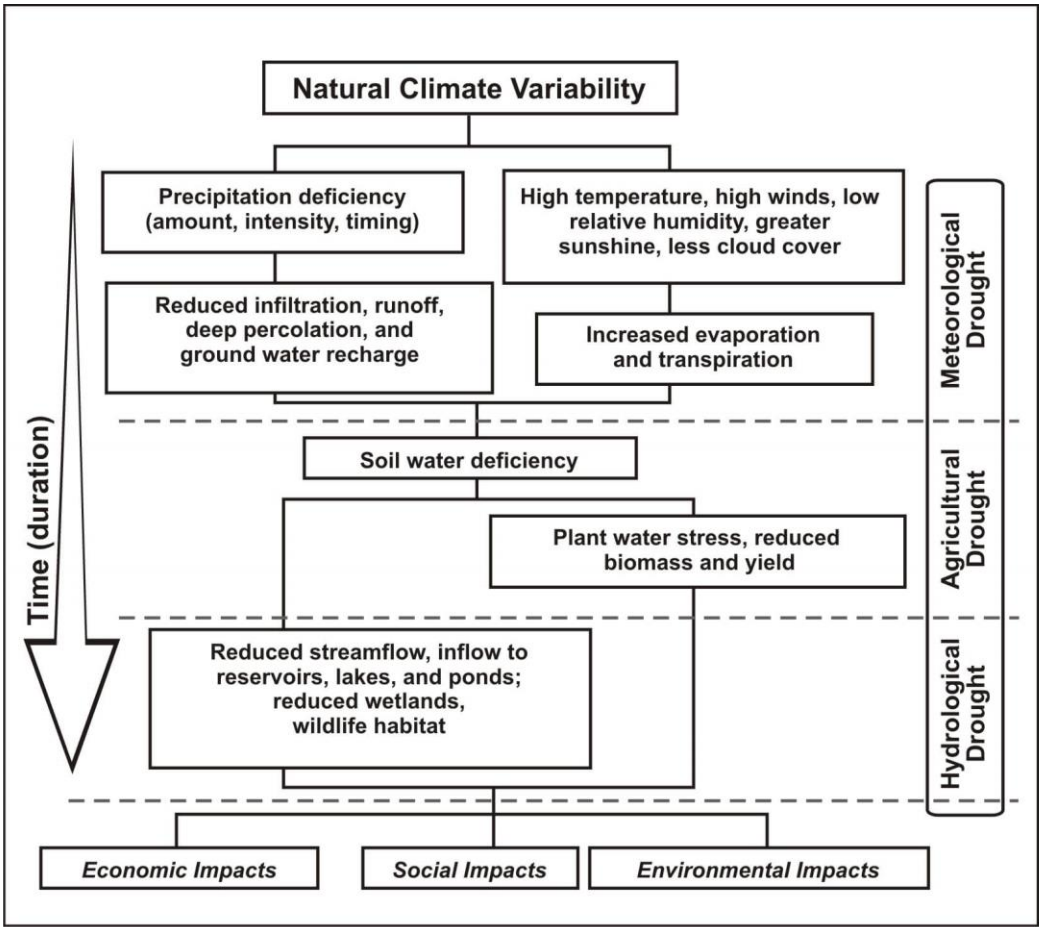

Figure 2 - Drought types, their characteristics and interrelations over time. Source: NDMC (see footnote)

[1] Available at: https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx (Accessed in August 10, 2019)

All those types can be seen as different dimensions of the same phenomenon. According to Wilhite & Buchanan-Smith (2005), meteorological drought, simply put, is a measure of dryness or precipitation deficiency that has occurred over a certain time in a region in relation with a similar period in previous years. That process is connected to other climatic variables, such as high temperatures, high winds, greater sunshine, among others, that diminish the total water available in soil for plants. At that point, an agricultural drought might begin, which is a process that also depends on other variables that have little to do with precipitation and are more closely connected to soil structure, soil water-retention capacity and plant water demand. Hydrological droughts occur when surface and subsurface water supplies become affected, usually long after the initial precipitation deficits were first detected. Finally, socioeconomic droughts is unique as it associates human activities with one or more elements of the other drought types. The association might be related to the supply and demand of a particular good that depends on precipitation or it may refer to the differential impact the drought had on distinct groups so separated by the resources available to them.

3.3 COPING, ADAPTATION AND VULNERABILITY

The concept of coping is often defined in terms of "coping capacity", that is, "the ability of a system (natural or human) to respond to and recover from the effects of stress or perturbations that have the potential to alter the structure or function of the system" (Burkett, 2013). It implies system attributes that precedes a disturbance, modulating how the system responds to it (Gallopín, 2006). That capacity is translated into "coping strategies" after the onset of adverse events, which can be understood as actions taken by affected people or communities to in the short and medium term to survive or return to normality (van der Geest & Schindler, 2017).

While coping is a response to immediate threats with focus on survival, adaptation dominates a more long-term approach, which includes learning and reinvention (Lavell *et al.*, 2012). Both concepts are interrelated and, sometimes, coping strategies even have been considered short-term adaptive strategies (van der Geest & Schindler, 2017). They can also influence the outcome of each other. For instance, adaptations may reduce the cost of coping, while successive uses of coping strategies can deplete resources that could favor adaption (Lavell *et al.*, 2012).

Vulnerability can be concisely defined as a “potential for harm or loss” (Cutter, 2013). However, in social and natural sciences, that concept can acquire many different nuances, often involving attributes such as exposure, stress, sensitivity and response capacity (Gallopín, 2006). Thus, vulnerability can be seen a function of how long and by what degree a system has been exposed to one or more stresses, to what measure those impacts were absorbed without further changing the system and what is the system ability to respond to those impacts.

In more specific terms, drought vulnerability is determined, according to Wilhite & Buchanan-Smith (2005, p. 12), by cross-sectional “micro- and macro-level factors.”. At the micro level, they are anchored on the household physical assets (land, cash and livestock) and the stronger and more diversified they are, lower will be their vulnerability. At the macro level, state and institutional strength and capacity to provide relief and the accountability of those structures to vulnerable populations are key.

While the determinants of drought vulnerability clearly play an important role in the array of possible coping and adaptive strategies available to farmers during a crisis, it is does not explain the order or sequence of actions taken by individuals. Indeed, farmers are a heterogeneous group that will respond with different management approaches based on farm characteristics, human resources and cognitive factors (Keshavarz & Karami, 2014). Those variables will shape what Keshavarz *et al*. (2010) identified as three drought management types in rural Iran: technical, psycho-economic, and integrated. In each of those approaches, the priority of strategies taken will change and so will their effectiveness.

4 STATE OF THE ART

The Mata Atlântica biome in Southeast Brazil has been the focus of numerous recent studies concerning land degradation, natural resources and ecosystem services.

Ribbe, Formiga-Johnsson, & Ramirez Duval (2019) have assessed water resources in the state of Rio de Janeiro. The authors describe a state in which water demand by burgeoning population centers, agricultural and industrial activities pressures a limited supply of renewable water sources, drawn mostly from a single river basin, creating a situation of water stress and increased exposure to hazardous weather events. To face those challenges, the political-institutional build-up following the Federal Water Law 9433/97, which included the creation of National Water Agency (ANA), the State Institute of Environment (INEA) and a greater participation of local municipalities and the civil society in water governance, was fundamental. However, despite the gains in technical and financial capacity building, severe problems regarding water security and management remains. Measures that could alleviate such problems include protection of springs and headwaters arising from inadequate land use, improvements in water infrastructure with better sanitation access and sewage treatment, the implementation of a technical base for management, amongst others.

The vulnerability of the Rio de Janeiro state to extreme weather events (EWE) is analyzed by Nehren, Kirchner, Lange, Follador, & Anhuf (2019). The intensive land use change following the arrival of the first European settlers destabilized slopes and changed river dynamics, leading to increased erosion rates, landslides, mudslides, flooding and river incision. Vulnerability was further increased in the 20th century as new land degradation processes following the expansion of urban areas, industrialization and agricultural land reclamation. Droughts up to that point were uncommon and mostly caused by overuse of water resources rather than a shortage of precipitation. That has been changing in the last few decades as climate change has modified rainfall regimes, increasing the likelihood of lengthened dry spells and heavily concentrated rainfall events.

Similar conclusions were found by Follador *et al*. (2018) when studying the biotic and abiotic impacts of climate change in the Atlantic Forest. The authors found that the Southeast, Midwest and Northeast regions are at an increased risk of longer droughts and loss of soil moisture over the next decades, which will trigger disruptions in the production of commodities, displacements and rearrangement in plant communities. The increase dryness of the weather would also decrease the risks of rainfall erosivity in those regions.

Although the general trend for Southeast Brazil might be of increased dryness, within the region those changes might manifest themselves in variegated—sometimes imbricated—patterns of increased and decreased rainfall. That affirmation was demonstrated by a study of climate variation in the state of Rio de Janeiro from 1979 to 2009 (Sobral *et al*., 2019), which calculated the Standard Precipitation Index (SPI) for the region using data from ninety-nine meteorological stations distributed over state territory. The results show an increasingly wet Northern region contrasted with a drier Mountainous and Center-South. However, for the vast majority of the state, trends were inconclusive or insignificant.

Those results were corroborated by a small-scale experiment in the micro-basin of Santa Maria/Cambiocó, in the municipality of São José do Ubá, Northwestern RJ (Noronha *et al*., 2016). Data from two precipitation stations, one covering the period of 1942-2005 and the other 1961-2013 were used to calculate the Rainfall Anomaly Index (RAI) for the catchment. There was no evidence of an increase in periods of meteorological drought over the years or of a change in the rainfall regime. The authors then suggest the increase in dryness might be related to land use and land use changes.

Soil and relief are also important drivers of land degradation in Brazil’s Atlantic Forest, as shown by Soares da Silva, Seliger, Sattler, & Heinrich (2018). Degradation processes will thus vary depending on the combination and value of its different variables. In the Paraná Basin, deep soils and heavily concentrated rainfall during the wet season favors the appearance of large gullies. In Northwestern Rio de Janeiro, lower precipitation—below 1200 mm— and gentler slopes reduce the probability of gully formation, but are susceptible to laminar erosion, especially in Acrisols exploited by grazed pastures.

Socioeconomic factors complete the equation of soil vulnerability to land degradation. They can be divided into two components, one historical, starting with the rainforest removal by Portuguese settlers, and one contemporary, concerning the overexploitation and mismanagement of pasture and crop lands under a climate change scenario. In the particular case of the state of Rio de Janeiro, the colonization of the hilly countryside by coffee plantations in the 19th century, followed by their abandonment and recolonization by livestock farmers is crucial to understand the current degradation processes (Nehren, Kirchner, Sattler, Turetta, & Heinrich, 2013).

Land and pasture degradation are intimately connected in Southeast Brazil. Pastures now cover around 21 % of the national territory, 35 % in the Atlantic Forest alone, of which 36 % and 21 %, respectively, show signs of degradation (LAPIG, 2017). In comparison, the Sattler *et al*. (2018) estimates 22,08 % of the national territory is degraded to a certain extent. The same authors argue pasture degradation in RJ is a direct consequence of improper grazing management practices in vulnerable areas. Pasture intensification on steep hills under heavy concentrated rainfall lead to vegetation cover loss, soil compaction, and, eventually, erosion, a situation aggravated by an absence of pasture grass management and vegetation rest periods.

Remote sensing is a powerful tool to track changes in soil cover and thus provide information on pasture degradation over large areas. A particularly interesting study used high-resolution composite image product (RapidEye and Landsat 5 TM SWIR bands) and fieldwork assessments for land cover classification and pasture degradation identification in the Guapi-Macacu watershed in RJ (Naegeli de Torres *et al*., 2019). The findings show that 41% of the pastures are located in slopes steeper than 10° and that 90 % of those are degraded. Almost all slopes steeper than 20° are degraded, with nearly 59 % of them moderately or strongly degraded.

A very similar result was obtained by Calegario *et al*. (2019) in the São Bartolomeu and Limoeiro river basins, Minas Gerais. Google Earth and LANDSAT 8 OLI images were used to model, based on the Normalized Difference Vegetation Index (NDVI), the degree of land use intensity (LUI), divided then into eight classes, the first five of which are related to different levels of pasture degradation. Nearly 97 % of the pastures were thus identified as degraded and almost 70 % of all pastures are heavily degraded or worse. More intense degradation was also associated with higher terrain, although slope degree was not identified. Curiously, complete soil exposure only occurred in 0.8 % of pasture area.

The chronic pervasiveness of pasture degradation called for the implementation of preventive and rehabilitative measures in the region. In that regard, the municipality of Itaocara in RJ was host to a pilot initiative who objective was to restore degraded sloped pastures in a dairy farm using bioengineered methods (Hebner *et al*., 2018; Sattler *et al*., 2018; Seliger *et al*., 2019). Parallel terraces and shrub lines using native species were applied and deemed successful in stabilizing the degraded slope, increase fertility and biodiversity, in conjunction with pasture rotation.

5 STUDY AREA

5.1 SOCIOECONOMIC DATA

Santo Antônio de Pádua and Cambuci are located in the Northwest region of the state of Rio de Janeiro, alongside the municipalities of Aperibé, Bom Jesus do Itabapoana, Italva, Itaocara, Itaperuna, Laje do Muriaé, Miracema, Natividade, Porciúncula, São José de Ubá and Varre-Sai. The estimated population is 42,359 inhabitants (2018) and the area of the municipality is 603.4 km². The municipality has a per capita Gross Domestic Product (GDP) of R$26,154.88 (in 2016) and a Municipal Human Development Index (MHDI) of 0.718 (36th position among 92 state municipalities), considered high and close to the national average of 0.727 (IBGE, 2018). Major economic activities include dairy and beef farming, the cultivation of rice, sugarcane and olives, and the extraction of mineral resources, mostly as ornamental stones (Pires, Carrisso, & Peiter, 2011).

The municipality of Cambuci is similarly large in extension, 558.3 km², but it has a much lower population, 15,496 in 2018. The per capita GDP as in 2016 was R$22,554.23, with a 0.691 MHDI, considered average (65th position in the state) in 2010. Agriculture accounts for a large portion of the GDP, with sugarcane, maize and dairy farming being the most important activities (IBGE, 2018).

Cattle raising activities are important in both municipalities. In Santo Antônio de Pádua, the total stocks have in the last decade being higher than in Cambuci, reaching a peak in 2007 (Figure 3). Currently Cambuci has more stocks than Pádua, following a slow growth starting in 2004.

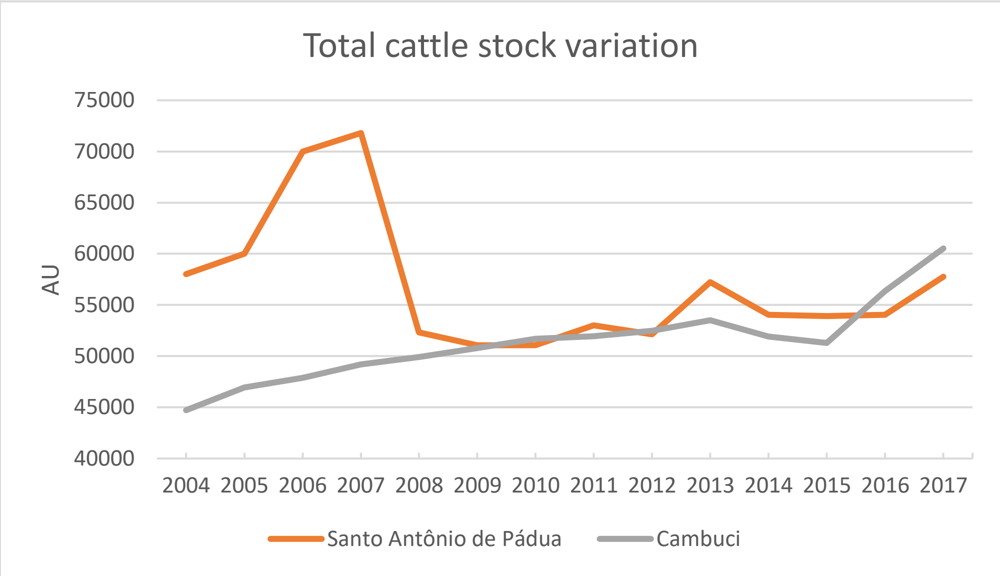

Figure 3 – Cattle stock variation in animal units (AU) over the years for Santo Antônio de Pádua and Cambuci. Source: IBGE

Milk production in Santo Antônio de Pádua oscillated considerably during the last decade, with three considerable dips occurring in 2012, 2014 and 2017, the last two of those years being considered drought years (Figure 4). Cambuci, on the other hand, has been constantly increasing its production without a single drop since 2004, currently overcoming Santo Antônio de Pádua in total volume.

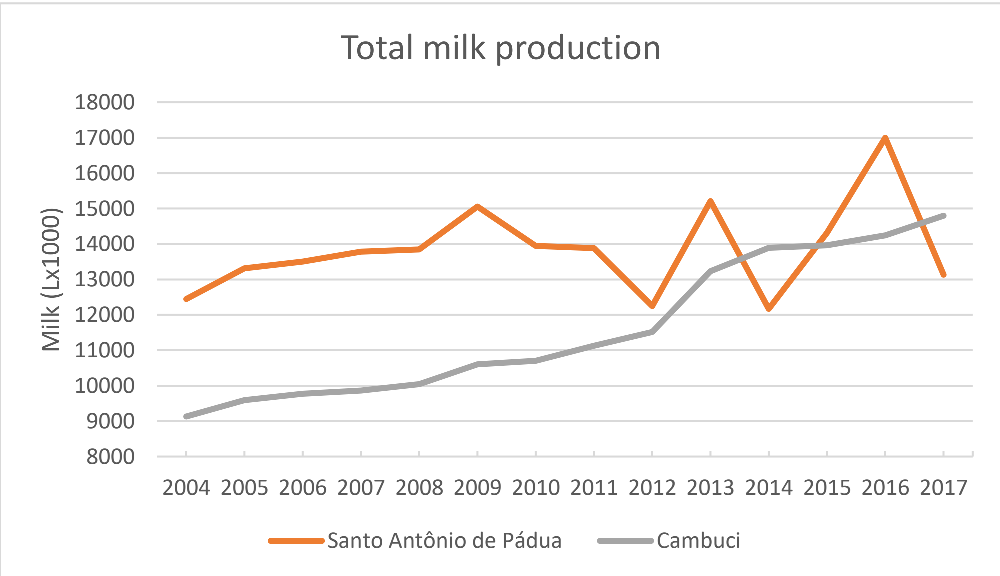

Figure 4 – Total milk production variation in liters over the years for Santo Antônio de Pádua and Cambuci. Source: IBGE.

5.2 Environmental Information

The municipalities of Santo Antônio de Pádua and Cambuci are located predominantly in what Lumbreras *et al*. (2004) would call Macro-pedoenvironment 1. They correspond to highly fertile areas with dissected relief, which would prime the area for the development of agriculture if not for the average to low water availability. Eutrophic Red Acrisols, Red-Yellow Acrisols and, less frequently, hydromorphic Planosols are the predominant soil types of the region. The first two types of soil dominate steeper slopes, while the third type associates with them lower-elevation rolling hills with gentler slopes.

The climate type is, according to the Köppen climate classification, *Aw*, with the rainy season during summer (November-April) and the dry season during winter (May-October). Median yearly precipitation is above 750mm and up to 1800mm (Ortega Gonçalves & Caldeira, 2005). During the dry season, monthly average rainfall is lower than 60 mm (Lumbreras *et al*., 2004). An ombrothermic diagram for the Northwest region of RJ measured from a ground station in the city of Iteperuna (Lat 21.2°W, Long 41.9°S, 123 meters above sea level) is provided by Figure 5.

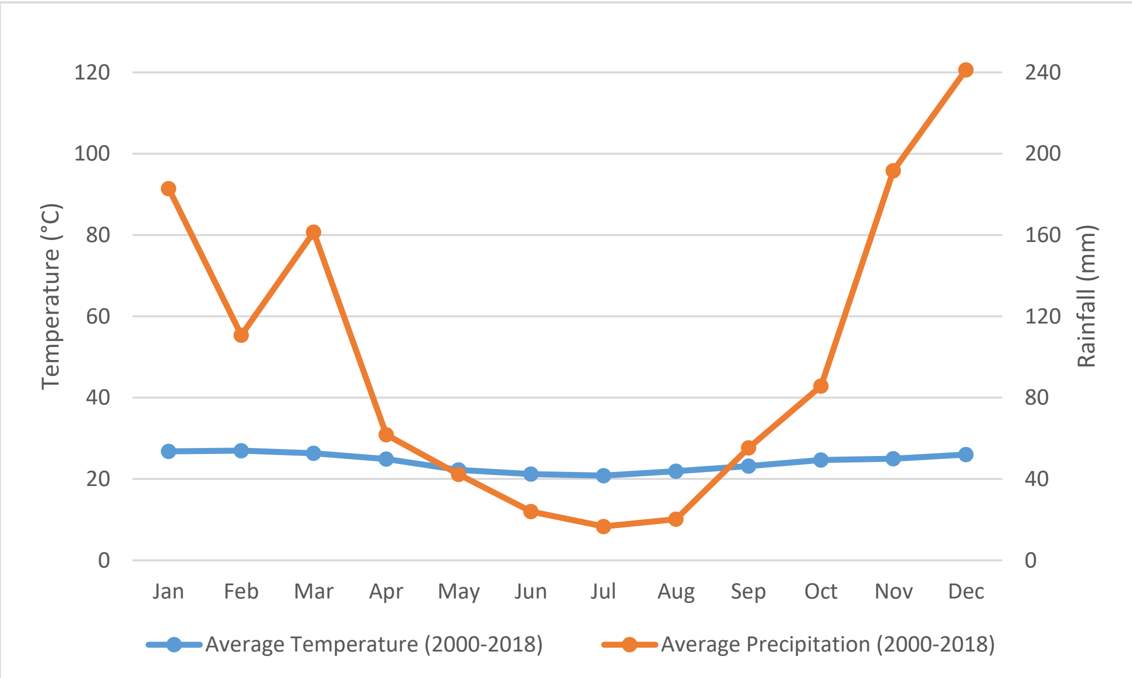

Figure 5 – Ombrothermic diagram for the Northwest region of the state of Rio de Janeiro. It shows the mean temperature and the mean precipitation for the period of 2000-2018. The dry season occurs between May and September. Source: INMET.

Lumbreras *et al*. (2004) argues that cattle grazing as the predominant rural activity in the macro-pedoenvironment 1 is a direct consequence of the rugged landscape and a climate characterized by marked rain seasonality. The consequences of such land use are, mostly due to inadequate managing, relatively low soil permeability and increase in erosional processes, the latter being compounded by the intense first rains usually falling when soil cover is already absent.

Climate change leading to larger dry periods followed by heavy precipitation have magnified the risk of erosion in an already vulnerable environment (Hebner *et al*., 2018). Current agricultural practices contribute substantially to such vulnerability, with overgrazing removing most of soil cover and allowing for large quantities of soils to be washed away to rivers and rivulets (Hebner *et al*., 2018; Lumbreras *et al*., 2004).

6 METHODOLOGY

In order to understand the impacts of a drought on the livelihoods of dairy farmers and their reactions to that hazard, a number of steps are necessary. The first involves a description of their production systems, which includes a characterization of their specific socio-ecological systems. Once the system is well defined, socio-economic and ecological variables can be identified and their value, when possible, calculated or inferred for different periods. Finally, farmers' reactions to the drought are identified and their outcomes are then associated with their production systems and the change in the measured variables.

There are a number of ways to achieve the proposed objective. For the purpose of this study, two methods were used: a survey and field observations. The choice of a survey was based on the criterion of economy of design (Creswell, 2014), allowing for the recollection of the bulk of the data using a single instrument, which fits inside the tight time and budget constraints of the project. Additionally, information regarding the coping strategies and general farm operational variables over time are nearly impossible to obtain from other sources, demanding then direct contact with the farmers.

Surveys can be cross-sectional or longitudinal, and data can be gathered using e-mails, interviews, the Internet, telephone, among other ways (Creswell, 2014; Fowler, 2014). Since longitudinal—data collection over time—surveys were impossible, the best choice was a cross-sectional study involving a single personal interview per farmer. That choice took into consideration the type of the population sampled—mostly rural, outside the range of cellphone or telephone coverage and with low literacy rates— and the open-ended question form, which often requires clarification and explanation. Additionally, personal interviews conducted in the farm allowed an opportunity to make observations directly, something that is not possible with self-reported questionnaires and telephone interviews. Other advantage is increased response rate, as interviewees feel more motivated to answer questions when in presence of the researcher (Fowler, 2014).

The downsides of personal interviews directly in the farms, however, are the time pressure it imposes on the researcher and the interviewees and increased costs. Regarding the former, personal interviews require significant traveling time from the researcher, as farms were often distant from the city center and only reachable through difficult to cross dirt roads. The relatively long interviews (between half an hour to one hour and half) were also taxing to farmers, subtracting time from their leisure or work time. The peculiarities of dairy production also meant that early morning interviews were likely to interrupt farmers during milking. Another factor to consider was the difficulty in locating the farms, which demanded the presence of local guides. Their daily schedules were significant in limiting the time and the number of interviews possible in any given week. Distance and dirt roads similarly affected the costs of the project, rising the demand for fuel and repairs. For every two full days of driving through poorly maintained dirt roads, one fuel tank of ethanol was required.

The limitations concerning the form of survey and question content affected sample size, the same with the initial study design based on modeling soil-related ecosystem services. As such, during fieldwork—from March 14 to April 11—sixteen farmers and five local authorities/experts were interviewed in total, of which thirteen were dairy farmers. The selection of farmer interviewees was dependent on three factors: the presence of secondary sources to corroborate interview data, the opinion of a local expert with extensive knowledge of the region's producers and opportunity. The first factor was mostly due to serendipity, as catalogued information concerning a number of dairy farmers was unearthed in the local EMATER office, creating an opportunity to cross-reference data from the interviews. The second factor, altogether with the presence of guides, allowed for a greater receptivity of the farmers to the interviews. The last factor was a direct consequence of venues opened after the first two weeks in the municipality, revealing actors and state initiatives that brought a new light into the rural dynamics of the region.

6.1 Interview design and structure

Questionnaire design included a broad number of themes, eleven in total, with the goal of increasing data serviceability. Each theme covered a number of items indicating the information desired from the interviewees, some of which formatted into questions (**Table 2**). Characterization of the dairy productive systems occurs in themes 1-6 and 9, while changes in ecosystem services and socio-economic variables appear in themes 1, 2, 3, 7, 8 and 10. Coping strategies and adaptation turn up in themes 4, 5, 6 and 8.

Interviews initially followed questionnaire order, but during fieldwork it was evident the open-ended nature of the questions and the interconnectedness of the themes meant that several items were touched by a single answer, creating considerable repetition. As a result, the researcher decided to pursue questions aligned with the responses given, reducing the reiteration of questions at the cost of an increased back-and-forth between them.

Table 2 – Questionnaire containing the main themes and items of the interviews

1. General questions	
a) Age	
b) Educational attainment	
c) Number of people living in the property	
d) Number of people working in the property	
2. Property	
a) History (how many years of ownership/use, the state before acquisition…)	
b) Size	
c) Legal status (owned, leased…)	
d) Productive area now and during the drought	
e) Water sources	
f) Type and quantity of animals raised	
a. How it varied in time?	
b. How many before the drought?	
c. How many after the drought?	
3. Production	
a) Milk yield over time	
b) Cattle raised for beef over time	
c) Other products – which?	
d) Inputs used before, during and after drought (quantity and monetary value)	
a. Fertilizers (which? E.g. organic, phosphate, etc)	
b. Labor	
c. Veterinarian	
d. Water	
e. Pesticides	
f. Fodder (which kind? How much?)	
g. Fuel (diesel, gasoline…)	
e) Goal – subsistence, market, etc.	
4. Management	
a) Irrigation (when? Installation and maintenance costs?)	Before, during, after drought
b) Pest control	
a. Weeds	
b. Others (which?)	
c) How pasture is managed? (Type of management? When?)	
a. Slash-and-burn? Rotation?	
b. Number of animals per hectare	
d) Technical level	
a. Machines (Which? How many? When are used?)	
b. Tools (Which? How many? When are used?)	
e) Manure	
5. Investment	
a) Facilities	
a. When? How many? Goals?	
b) Water pumps	
c) Irrigation system	
d) Milking machine	
e) Anaerobic digester	
f) Solar panels	
g) Cattle identification system	
h) Others – which?	
i) Future perspectives	

j)	Financing source
6.	**Finances**
a)	Alternative sources of income
b)	Sales (land, animals, machines, automobiles, etc)
7.	**Land degradation**
a)	Productivity loss over time
b)	Erosion – increased? Lost land?
c)	Animal health
d)	Pasture health
e)	Relationship with pests
f)	Protective measures
8.	**Drought**
a)	Personal history
b)	Effects inside the property a. Which were the affected areas? b. Which animals were most vulnerable?
c)	Effects on inputs a. Which increased or decreased usage?
d)	Effects on production a. Did it change? By how much?
e)	Coping a. What was done? Water? Fodder? Investment?
f)	Outside help a. Who? How much it costed?
g)	Adaptation a. Any changes in practices afterwards?
h)	Recovery a. Did it happen? Why?
9.	**Technical assistance**
a)	Enrollment in an assistance program a. Which? Of what kind? How often?
b)	Degree of adoption of practices
10.	**Sustainability**
a)	Adoption of soil conservation practices a. Which? Why? When?
b)	Preserves part of the property
c)	Adoption of silvopastoral practices a. Which? Why?
d)	Adoption of sustainable practices a. When was the implantation? b. Difficulties and costs? c. Abandoned? Why? d. Perceived costs and benefits for implementation e. Adoption decreased the impact of the drought?
11.	**Future perspectives**
a)	Desire to continue with dairy farming
b)	How the drought affected future plans
c)	Do you see a future in dairy farming in your municipality?
d)	Who will inherit the farm?
e)	Do you wish to invest in the production? Why?

Very little information concerning local agricultural practices and ecosystem services exists for the municipality of Santo Antônio de Pádua, making the selection of the most appropriate indicators a hazardous process. In that regard, the pioneer work of Mergner (2018) was of vital importance by creating the first set of demonstrable interview-based indicators for ecosystem services in the region. Therefore, many of those were incorporated and adapted to this work. Items specific to farm system analysis and production variables came from elsewhere, with the main categories taken from Doppler (2000) and Stroosnijder & van Rheenen (2011) and the specifics completed after the first three interviews.

The first three interviews were key to acquaint the researcher to the particularities of the farming systems in the region. This learning experience was incorporated into the next interviews in the form of more detailed questions. For example, after it became clear irrigation systems were relevant and farmers able to describe its workings, that information was used to broach the topic to other farmers, eliciting more detailed feedback. Similarly, when certain lines of inquire proved to be confusing or too sensitive to interviewees, it was de-emphasized from the next interviews. Examples of the former are items 10.c) and d), with farmers showing little understanding of the topic. Of the latter, questions containing total earnings in Brazilian real (R$) were quickly dropped as respondents felt uncomfortable answering them.

6.2 OBSERVATIONS

Observations were a complementary tool to the interviews. They took place in the farmers' property, usually during the application of the survey, and included a rapid evaluation of signs of land degradation and the general state of the productive unit. The content of such observations sometimes were used to elucidate elements in the respondents' discourse or to confront apparently contradictory statements e.g. farmers' claims of the absence of erosion against clear signs of erosion inside their lands.

6.3 RESULT ANALYSIS

The process of transcribing and translating interviews is laborious and time-intensive. The preferred method, thus, was a partial transcription, in which relevant information was extracted and added directly into a data matrix. The process only included interviews from the thirteen dairy farmers, as the others' contents were out of the scope of the analysis. Data was then separated into themes, tabled and presented with complementary descriptions, comparisons and field observations.

The analysis did not include the entire material of the selected interviews. The vastness and complexity of the data gathered exceeded the limitations of this work, therefore great care was taken to systematize only information that fitted the criteria of relevance, consistency and utility. Topics outside those criteria were either left out of the analysis or deployed loosely on the discussion.

7 RESULTS

In total, 11 dairy farmers were interviewed in Santo Antonio de Pádua and two in the nearby municipality of Cambuci. On four occasions interviews occurred in the presence of relatives (F3, F11, F13) or spouses (F4) who were actively engaged in the management of the farm. Overall, five farms are co-managed with the help of family members, including the only one in which a female had an active voice in the process. Average age, taking into account the age of co-managers when applicable and known, is of 56.6 years old, revealing an ageing rural population.

Only one farmer had a college degree, and two, including the female co-manager, had a professional degree. Of the others, seven achieved primary education and four, secondary education. When co-managers have different educational achievements, only the highest degree was shown in **Table 3**, as is the case of F4. Startling, the younger generation seems no more likely to have attained higher levels of education than the older ones, indicating a level of stagnation in this particular area.

Place of residence was more often than not the farms themselves, occurring in eight out of the 13 cases. One particular farmer (F6) divided his time between the farm and the townhouse. In one instance, part of the farmer's extended family lived in the property, although the farmer himself did not (F1). Those who did not live in the farm had a house either in town or in one Santo Antonio de Pádua's districts. No properties, with one exception (F1), had resident employees. In three accounts, farms are inhabited solely by couples (F6, F8, and F12). Only F4 and F13 had young children living in the farm, with F3, F7 and F9 sharing the farm with the extended family.

All farmers, with one exception (F2) own or share ownership of their lands. The exact configuration of those land titles is often unclear and the boundary between owning and possessing the land becomes particularly blurry when taking into account complicate webs of inheritance, lending and leasing between relatives. Although many farmers state they own their lands, further inquiry reveal that part of the land is owned or used by parents, siblings or children. The only farmers who unambiguously own their lands are F4, F6, F7, F8 and F12. F3 stated ownership belongs to his father, who also took part of the interview and is a co-manager of the property. F1 stated he owns the property, but the presence of relatives residing in the farm, his father included, indicates a more complicated ownership structure.

Table 3 – General farmer information

Farm	Age	Educational attainment	Place of residence	Resident family	Resident employees	Legal status
F1	74	College	Town (P)	3	4	Owner
F2	59	Professional	District (P)	0	[redacted]	Lease
F3	46/84	Primary	Farm (P)	4	[redacted]	Owner
F4	57/36	Professional	Farm (P)	5	[redacted]	Owner
F5	36/NA	Primary	Farm (P)	4	[redacted]	Family ownership
F6	46	Secondary	T/F (P)	2	[redacted]	Owner
F7	71	Primary	Farm (P)	9	[redacted]	Owner
F8	73	Primary	Farm (P)	2	[redacted]	Owner
F9	59	Primary	Farm (P)	5	[redacted]	Owner & leaser
F10	66	Primary	Town (P)	0	[redacted]	Family ownership
F11	40/44	Secondary	District (P)	0	[redacted]	Family ownership
F12	62	NA	Farm (C)	2	[redacted]	Owner & leaser
F13	53/NA	Secondary	Farm (C)	4	[redacted]	Owner

Even in cases where ownership is unambiguously known, more complicated land use arrangements abound. Farmers, in addition to their own lands, can also tend the land of siblings, who no longer live in rural areas, in exchange of the total or part of the production in that area, F6 being an example of the former and F12, of the latter. Other arrangements include split terrains, in which farmers own two non-contiguous properties, moving cattle back and forth between them, which is the case of F7 and F8. There are also occurrences of accessing neighboring pastures (F6) with the agreement of the respective owner, but the specifics of such transactions were not revealed.

A family ownership occurs when more than one adult family member own or might own, in a shared agreement or as individuals, part or the entirety of the studied property. The farm remains a functional unit and its administration remains inside the family. It is an ambiguous ownership situation, which often raises delicate questions about inheritances and may feed into suspicions and mistrust. As such, interviewees were reluctant to clarify the relationships that conform their particular ownership situation. That particular ownership regime takes place in F5, F10 and F11, although the specifics vary between them.

In F5, father and son run day-to-day operations, with the occasional help of sister and mother. It was unclear if a one family member owned the entire land or if it was a patchwork of properties. Some neighboring farms belong to close relatives and there are traces of a functional relationship between all those units, which are not limited to ownership of the property. The water sources are considered communal and even the access to the interviewee's farm must pass through their relatives' land.

F10 offers a different circumstance, in that land is owned by several siblings who no longer live in the rural area and left the stewardship of the property to a single brother. The specifics of such arrangement is unknown and so is the ownership relationship between family members. Regardless, the farmer is the singularly responsible for the management and administration of the entire property.

One of the most complicated family ownership arrangements takes place in F11. Scions of a prominent landowners of old, the two siblings manage together two relatively large properties regardless of specific ownership status. Indeed, it is hard to pinpoint which part of the lands is owned by them individually, which part is owned between them, if any, and which part is still owned by their mother.

The case of F13 is *suis generis*. The farm was left in the hands of the son while the father worked as a sharecropper elsewhere, returning once the milk business took off. In this particular case, it is clear the son owns the business, but the land ownership situation is murkier.

Property size was a variable that contained a certain degree of imprecision (**Table 4**). Many farmers still measure their properties in *alqueires*, a colonial-era area unit that is no longer officially accounted by the Brazilian government (BRASIL, 2013). Older governmental documentation (IBGE, 1948) describes the many possible values of the *alqueire* in meters and hectares in many regions of the country, which shows considerable variation. For the state of Rio de Janeiro, it is assumed the *alqueire* used is the *alqueire mineiro*, in which one unit equals 4.84 hectares. Thus, all the measures in *alqueires* were converted into hectares using that ratio.

Table 4 – Property size and subdivisions in hectares

Farm	Farm area (ha)	Used area (ha)	Productive area (ha)
F1	230	NA	30
F2	121	96.8	10
F3	96.8	87.12	6
F4	19	NA	2.8
F5	18	14	2
F6	19.36	19.36	0.35
F7	19.36	19.36	15.49
F8	19.36	19.36	15.49
F9	9.68	NA	4.5
F10	29.04	9.68	0.675
F11	338.8	196.02	186.02
F12	16	13.2	0.4
F13	52	4.5	4.5

The average property size of the interviewed farmers was of 76.03 hectares, with the smallest being 9.68 hectares and the biggest, 338.8 hectares. If the farmer had more than one property, the area considered was the one that concentrated most of the production system (F7, F8). If production occurred in both areas, they were both accounted in the final tally (F11).

Used area was not always known, but in some cases, it was estimated from other details in the interviews. In the case of Farmer 2, 20% of the property is part of the legal protected area, meaning that production could only take part in the remaining 80% of the area. The same logic applies to F3, who claims 90% of usage, and F11, who claims 100% usage in the first property and 30% usage in the second. F7 and F8 claimed to use a 100% of their property for productive activities, which does not correspond to on site observations.

For productive area, only reserved grazing pastures for dairy cows were considered. Those are usually lowlands (F1, F2, and F13), paddocks (F4, F5, F6, F10, F12, and F13) or creek margins (F3). For F1 and F2, it is assumed the entire lowland area is productive pasture. F12 total pasture area is possibly much bigger than the stated productive area, which encompasses only the paddocks. F3's productive area corresponds solely to paddocks found in both margins of the creek, and do not take into account those in hilly areas that are used during the wet season. F10's value was calculated based on a stated paddock size of 15x15 m, 30 in total. A similar calculation was performed for F6, although here paddock size was assumed 15x15 m and not given. To estimate F11's figures, used area was subtracted from the area dedicated to sugarcane and forage grass (10 ha). It was estimated that pasture are comprised 80% of the land of F7 and F8, based on observational data. Productive area for F9 included the grass and sugarcane fodder areas, as the farmer lacks proper pastures.

7.1 ECONOMIC ANALYSIS

7.1.1 Productive system characterization

The interviews and visits to dairy production systems in the area allowed for their tentative separation into three broad categories based on management techniques and inputs used: traditional, mixed, technical systems.

Traditional systems (F7, F8, and F11) are based on continuous grazing, where pasture separation, if present, is informal and based on landscape features. Forage grasses, which include Napier (*Pennisetum purpureum*) and Guinea (*Panicum maximum* cv. Mombaça), and sugarcane provide supplementary fodder for the dry season. Rainfall is the main source of water for the pasture, but small-scale irrigation can be provided for forage grasses. Organic (manure) and chemical fertilization (urea) is possible in fodder production, same with soil pH correction with limestone. Weeding is done manually and there is no use of pesticides and herbicides. Milking occurs only once a day. There is no long-term vision in production and investments are haphazard and reactive.

Technical systems (F12 and F13) are based on intensive rotational grazing, in which pastures are carefully separated into a series regular paddocks that are exploited according to a grazing schedule. Those systems were initially implemented with the aid of a technician, usually a veterinarian part of the Balde Cheio program. The dry season is managed with sugarcane and reserved pasture, forage grasses being discouraged. Farmers perform annual soil analysis and the results guide fertilization and soil pH correction. Urea is applied daily after cows leave the paddocks, which demands the use of an irrigation system in the absence of rainfall. Herbicide and pesticide sometimes are used, although in a limited way. Reproduction is carefully controlled, with reproductive cycles frequently monitored, which results in high cow pregnancy rate of above 70% over the whole stock. Milking occur twice a day. There is emphasis in planned long-term investments and improvements in production.

There are indications mixed systems (F1, F2, F3, F4, F5, F6, F9 and F10) may have evolved in the region as an indirect consequence of the introduction of technical systems by the Balde Cheio program in 2005. Many of the innovations brought by the program spread to nearby dairy farmers, who adopted bits and pieces of it according to their own convenience. The result is a kaleidoscope of practices that unite characteristics of traditional and technical systems in peculiar ways.

In general, those systems retain the traditional uses of forage grasses and sugarcane, *ad extremum* leading to F9's near zero-pasture system. Pasture is separated into more or less defined paddocks and irrigation is widespread, but their usage are sometimes restricted only to the dry season. There is no constancy in soil analysis, which means fertilization, both chemical and organic, and soil pH correction often occur haphazardly. Urea usage is dependent on irrigation practices and can sometimes occur in larger intervals of time than in technical systems. Weeding is often manual, with pesticide and herbicide being used as needed. Milking occurs, like in traditional system, only once daily and cows' reproductive cycle control can vary widely.

Three farmers inside the mixed system group are examples of abandonment of a technical system. F2, F4 and F10 were once part of the Balde Cheio program, but for a variety of reasons, depending on who is asked, decided to drop the technical assistance and walk their own paths, with different degrees of success. F4 still manages their system very closely to a technical system, being perhaps the closest mixed system to approach it. F2 retains many of the practices taught by Balde Cheio's technicians, but slid back to once-per-day milking. F10 initially ditched a paddock group, then the irrigation system following the drought and now only produces a fraction of his peak years.

7.1.2 Inputs and outputs

The main inputs used by dairy farmers before, during and after the drought are summarized in **Table 5**. Values that were calculated based on estimates given by the farmers are marked in red. F12's data corresponds to the farmer's own ledger. F13 data was not recovered and therefore not presented.

It is noticeable all farmers, with the exception of F3 and F8, use one form of concentrate or another to increase milk yields. Usually, energy and protein concentrates are bought separately and mixed at home, using different proportions depending on the farmers' objectives and circumstances. F1 was the only concentrate-using farmer who did not, initially, mixed his own feed, preferring to buy them from commercial brands (120 sacks/month), only changing during the height of the drought.

Fubá, a kind of cornmeal similar to maize germ meal (Dias Paes, 2006; Duarte, 2011), is the foremost energetic concentrate, occurring in all cases, except F1. Of the concentrates, it is the least expensive one and used in generally in great quantities. The *farelo de soja*, a type of soybean meal, on the other hand, is more expensive and therefore used in lesser quantities. *Farelo de soja* and *fubá* are commonly used together, but F7 and F9 use *farelo de trigo* (wheat bran) in place of soybean.

Technical systems (F12, F13) use ratios of soybean meal to cornmeal ranging from 1:5 to 1:7. That is also the case for two ex-technical systems, F10 and F4. Mixed systems use a bigger proportion of soybean meal, going up to 1:4 (F6) or even 1:3 (F5).

Table 5 – Principal inputs used by class and volume and their variation around the drought year of 2017 for each farmer

Inputs (vol.)		Quantity	Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Cattle	Cornmeal	Sacks/month	<2016		Yes		Yes	15	Yes	Yes	0	Yes	13	150	51.25
			2017		0	0	Yes	20	3.63	5	0	↑	17	↑	69.59
			2018		Yes		65	15	4.54	3	0	Yes	5	150	70.83
	Soybean meal	Sacks/month	<2016		Yes		Yes	5	Yes	0	0	0	2	50	7
			2017		0	0	Yes	10	2.61	0	0	0	3	↑	8.83
			2018		Yes		10	5	1.63	0	0	0	1	50	10.83
	Rock salt	Sacks/month	<2016	40	Yes		Yes	Yes	Yes		6	0	1	10	0.75
			2017		Yes		Yes				↑	0	1	↑	0.5
			2018	10	Yes		Yes	3	Yes		6	0	1	10	1.25
	Table salt	Sacks/month	<2016								18	1	1	Yes	0
			2017								↑	Yes	1	Yes	0.17
			2018							Yes	18	1	1	Yes	0.42
Soil	Urea	Sacks/month	<2016		Yes		Yes	1.67	0.25	0.167	0		Yes	0	1
			2017	0				↓	Yes	0	0		0	0	4.5
			2018	100	Yes		3	1.67	0.25	0	0		0	0	4.67
Labor	Daily	Days/year	<2016			0				10			10.5		
			2017			0				10			10.5		
			2018			0		50	8	10			10.5		9
	Hourly labor	Hours/year	<2016			0				10					
			2017			0				10					
			2018		60	0	2			10					11
	Permanent	nº	<2016	10	0	0	0	0	0	0	0	0	0	0	0
			2017	4	0	0	0	0	0	0	0	0	0	0	0
			2018	4	0	3*	0	0	0	0	0	0	0	4	0

Values for F12 were extracted directly from the farmer's ledgers and the sum of inputs used each month divided by the total number of months in a year. Values in red represent estimates. No measures were taken for F13. Empty cells mean unknown usage. Calculation of the number of sacks in F6 used the bulk densities of maize germ meal and soybean meal **(New, 1987)**.

Table 6 – Estimated value in R$ of main inputs and their variation around drought year of 2017 for each farmer

Inputs (R$)		Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Cattle	Cornmeal	<2016					9780					8476	97800	26655
		2017		0			13040	2365.98	3260			11084		30407
		2018				42380	9780	2957.47	1956			3260	97800	37655
	Soybean meal	<2016					4800					1920	48000	6341
		2017		0			9600	2509.06				2880		7567
		2018				9600	4800	1568.16				960	48000	11407.5
	Rock salt	<2016	36000									900	9000	991
		2017										900		1062
		2018	9000				2700			5400		900	9000	1285
	Table salt	<2016								3240		180		0
		2017										180		153
		2018								3240	180	180		62
Soil	Urea	<2016						300	200					2860
		2017	0										0	4436
		2018	120000			3600	2000	300						5131
Labor	Daily labor	<2016							600			630		0
		2017							600			630		0
		2018					3000	480	600			630		2760
	Hourly labor	<2016							975					1080
		2017							975					900
		2018		5850		195			975					
	Permanent labor	<2016	132000											
		2017	52800											
		2018	52800		36000								72000	

Calculations, except for F12, are based on averages of base prices given by farmers. Urea – R$100; cornmeal – R$54.33; soybean meal – R$80; mineral salt – R$75; salt – R$15; hourly labor – R$97.5; daily labor – R$60. Permanent labor assumed a monthly rate of R$1100 per employee for F1. F3 admitted paying a monthly rate of R$1000; F11 pays in total R$6000 per month for permanent labor. F12 values are based on farmer's own annotations.

The only traditional system using soybean meal (F11) also uses a 1:3 soybean meal to cornmeal ratio. The difference between systems also shows during drought years, in which ex-technical systems would reduce the proportion of soybean meals (F10) in the feed while mixed systems it would increase (F5 and F6).

Technical systems (F12, F13) use ratios of soybean meal to cornmeal ranging from 1:5 to 1:7. That is also the case for two ex-technical systems, F10 and F4. Mixed systems use a bigger proportion of soybean meal, going up to 1:4 (F6) or even 1:3 (F5). The only traditional system using soybean meal (F11) also uses a 1:3 soybean meal to cornmeal ratio. The difference between systems also shows during drought years, in which ex-technical systems would reduce the proportion of soybean meals (F10) in the feed while mixed systems it would increase (F5 and F6).

Salt usage is a consensus amongst all farmers, although there is some confusion concerning which type, rock or table salt, is used. There are four instances in which both kinds are employed (F8, F10, F11, F12), but only in two (F10 and F12) the proportions are known thorough the entire period. Farmers F1, F2, F4, F5, F6 and F7 confirmed the usage of at least one type of salt, although only F1 and F5 gave hints of the quantity spent. F3 did not mention salt, therefore making it impossible to determine which kind is used. Salt application increased during the drought in two properties, F9 and F11. Rock salt use decreased comparing the pre-drought year and the post-drought year in F1.

Farmers were unforthcoming concerning urea usage, with the only complete dataset coming from F12's ledgers. Still, it is possible to observe its use is widespread, even though it declined in at least three occasions (F1, F5 and F10) during the drought. In some cases, it was not possible to determine application as farmers (F3 and F9) did not mention urea in the interviews. It is also unknown if F2 and F4 interrupted its usage during drought years.

Based on the quantity of inputs, it was possible to calculate the total yearly cost based on average unit cost for each one of them. **Table 6** shows the results of those calculations and compares them to the more refined aggregated monthly costs present in F12 ledgers. It is clear concentrate costs, in particular cornmeal, is the largest expense component amongst the main inputs used, followed by urea. The costs of holding a permanent labor force are also substantial, as seen in F1 and F11.

Hourly labor mostly refers to tractor hours, usually costing from R$80 to R$120, with an average of R$97.5. F2 used ten tractor-hours to plant maize and then fifty to harvest, at a cost of R$110 per hour. In total, F2 claims that to produce 100t of silage, it costed him R$10000 in 2018, accounting labor, planting and seeds. F3 use of daily labor is similar to permanent labor, as his three daily workers happen to be in the farm at least thrice a week and are often paid monthly wages (R$1000) if they work 20 days per month. F11 employs four permanent laborers, with a total cost of R$6000 per month, and three daily laborers for an undetermined amount of days a month. F1 used to employ ten permanent laborers, firing six during the drought. It was assumed each worker received a monthly wage of R$1100.

Weeding is the main tasks performed by daily labor (F5, F6, F7, F10, F12), and is usually performed during the course of a week, once a year. Hired workers can also help with fencing (F5) or other undetermined tasks (F8). The use of daily workers is often limited to the task, so it is unusual for farmers to use them more than two weeks per year, as is the case of F5. Daily wages vary with time and between the different regions of the municipalities, ranging from R$50 to R$70 a day worth of labor. For the purposes of calculating their cost, an average of R$60 was assumed for all farmers.

The basic output of dairy farms is, naturally, milk. However, some farmers have other outputs, namely yoghurt and eggs. The total amount of outputs per farm and their total yearly value can be seen in **Table 7**. The quantity of milk produced daily by each farm was extracted from interviews, with the exception of F12's 2016 and 2017 data, which came from the technician's control ledger.

Milk prices are yearly averages calculated from CEPEA's (2019) historical monthly series sorted by region, the Rio de Janeiro state. They are net prices, paid directly to producers and discounting taxes and freight costs. CEPEA distinguishes three net prices, encompassing low (≥200 L/day) and high (<2000 L/day) volume producers, and a total average. Since most farmers interviewed were low volume producers, that average was preferred, except in F1, F11, F12 and F13, where the total average was used to reflect their higher production levels. F12 is a particular case as its values for 2016 and 2017 were extracted from the ledger, and total average was used for 2018. The same average was chosen for F2's base year (2012).

Dairy production is a continuous business, occurring every day of the year without pause. Yoghurt production in F3 occurs every three days, as the necessary volume of milk accumulates. In both situations, intercalary years were taken into account to calculate the yearly value of each production. Yoghurt prices were given by F3, namely R$0.75 a unit containing 0.125L. It was assumed F6's production of eggs would remain constant during the year and that their weekly sales occur without interruption.

Table 7 shows a clear decline in milk production for most farmers, with a couple of exceptions. F10 affirmed to have produced the same amount of milk as the year immediately before the drought and F12's production, show in his ledger, pointed to an increase.

The only farmers who did not provide information on daily production of milk throughout the entire period were F4, F11 and F13. It is interesting to note F3's income from yoghurt has increased despite producing the same quantity of milk before and after the drought. For comparison, if F3 had sold his milk directly to the market, his earnings in 2018 would have been R$59,678, or 81.5% of his yoghurt earnings. F6's total amount of eggs sold during the year amount to nearly one-fourth of his earnings in the year of 2016, and nearly one-third in 2018.

Table 7 – Quantity and value of outputs for each farmer around the drought year of 2017

Outputs (vol.)	**Units**	**Year**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**
Milk	L/day	<2016	550	400	150		120	80	60	50	22.5	115	1000	216	550
		2017	475	50	55		80	45	30	35	8	115		259	
		2018	200	115	150	375	120	60	70	50	16	40	700	255	800
Yoghurt	L/day	<2016			37.5										
		2017													
		2018			100										
Eggs	Dozens/week	<2016						25							
		2017						25							
		2018						25							
Output (R$)	**Value (x1000)**	**Year**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**	**F12**	**F13**
Milk	R$	<2016	231.5	109.8			43.5	29	21.7	18.1	8.2	41.7	420.9	98	23.2
		2017	195.9	18.4			29.5	16.6	11.1	12.9	3	42.4		113.4	
		2018	92	45.8		149.2	47.7	23.9	27.9	19.9	6.4	15.9	321.9	117.3	367.9
Yoghurt	R$	<2016			27.5										
		2017													
		2018			73.2										
Eggs	R$	<2016						10.40							
		2017						10.40							
		2018						10.40							

7.1.3 Stocks

Cattle stocks are a measure of the productive capacity and one of the major drivers of input demand in dairy farming. They also act as a reserve of value and a medium of exchange. The total number of animals and the total number of cows before, during and after the drought are resumed in **Table 8**.

Cattle stocks are subject to considerable variation during the year, as some animals are lost to old age or accidents, others are sold, and new ones are born or bought. The values in the tables are thus yearly averages. Values for F12 and F13 are mostly derived from ledgers compiled by their technician. For them, the only values given during the interview are 2018's number of lactating and total cows. F13's pre-drought values refer to 2013's stocks, as his ledgers only went until 2014. Total stock by F13 assumed a constant average of calves, heifers and other animals over the years and no net cattle losses during the drought.

Also relating to 2014 are F3's pre-drought values, which were inferred from a 30% reduction of the stocks starting in 2011. F7's 2017 values were inferred from the number of animals lost during the drought, of which five were cows.

The incompleteness of data regarding the years before 2018 makes difficult to detect a trend in cattle variation by the numbers alone. At least three farmers experienced decreasing stocks during the drought (F3, F6 and F7), with two maintaining their numbers (F18 and F10), and two others increasing their animal headcount (F12 and F13). Post-drought stocks show a recovery for F2, F3 and F6, with the first two overcoming even pre-drought stock count.

A diminishing in the total stock count can happen either through losses or through sales. Some farmers offered numbers regarding both variables, with F2 and F5 emphasizing the number of animals sold during the drought and three others (F7, F8 and F11) highlighting average sale numbers. Five farmers admitted losses in 2017, with F8 suffering the biggest percentage loss regarding his total stock.

Table 8 – Animal units for each farmer around the drought year of 2017

Stock	Year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
Cow stock	<2016		20				17	18			9	?	23	39
	2017			25				13			9	?	24	49
	2018	80	30	30	37	14	15	16	16	9	9	107	25	49
Total stock	<2016	400	50	98				70	33		9	?	49	71
	2017			70				60	33		9	?	50	80
	2018	200	70	120	42	80	31	60	33	12	9	600	50	80
Sold stock	<2016							5	2.5			50		
	2017		20			10		5	2.5			50		
	2018							5	7			50		
Lost stock	<2016					8								
	2017					4	2	10	6			22		
	2018													

There are many reasons for cattle losses. For instance, F5 blamed his particular losses during 2016 and 2017 to fatal accidents, e.g. snakebites and falls. Similarly, F2 faults old age for losing two animals in 2017. Farmers F7, F8 and F9 held the drought of 2017 accountable for their dead animals, in particular by drying the reservoirs and exposing the sticky mud below, a deadly trap for thirsty bovines.

7.2 ENVIRONMENTAL ANALYSIS

The most common water resources farmers have access in the region are rivers, creeks, reservoirs, springs, artesian wells and dams. **Table 9** summarizes the presence and probable number of such resources according to the interviewees.

Table 9 – Type and quantity of water resources for each farmer

Farms	River	Creek	Reservoir	Spring	Artesian well	Dams
F1		1		>1		>1
F2		1	2			4
F3		1				>1
F4			2	1	1	
F5			7	4		
F6		1	4	1	1	
F7		1	2	1	1	
F8		1	2	1		
F9		1	1			
F10		1	1		1	
F11			2	6	1	
F12			≥1	2	1	
F13			2	>1	1	

Absent sources were painted in black and uncertain values bigger than one are represented as >1. None of the interviewed farmers' land cross any known river, but many are crossed by small creeks, termed *valão*. Of those, their riparian zones are mostly degraded and covered in pasture, with the exception of F1, who states the zones are preserved, and F3, where the area is covered with one row of trees. Those particular farmers are against expanding the riparian forest, arguing that it would take out their best and most productive land. The other farmers do not recognize the importance of the riparian zone and do not associate its protection with maintenance of water level during the dry season or in case of a drought. Farmer 6 do not use creek water for any agricultural activities. The same creek crosses F7 upstream and F8 downstream.

Reservoirs are wide dirt pits dug on earth to store water for later use, usually during the dry season and they can be filled by springs, rainwater or manually with the use of water pumps. Reservoirs are often called "poço" or, more commonly, "açude" in the local parlance, the latter creating considerable confusion as *açude* technically refers to a dam and in many situations, no such dam exists. Therefore, an attempt was made to distinguish both terms based on observation of the water sources and questions relating to origins of the water coming into the *açude*.

The importance of reservoirs is revealed in their ubiquity. Only four farms do not have them, and two of those have dams to provide the same utility. In F2, they feed the irrigation system and one of them supposedly has a 200-m³ capacity. F4 built two, one in 2009 with 6000 m³ and another in 2012 with 18000-m³ capacity. F5 inherited four out of his seven reservoirs from the previous owners, building the last of the remaining three in 2013. F6 remember when the first reservoir was built in 1989 and how he commissioned the newest one, in 2018, with the aid of the town hall. All his reservoirs are fed by underground spring water. F7 also has his reservoir connected to spring water, same with F8, who built his first in 2009 and his newest in 2016, in answer to decreasing creek water levels. F8 does not know how deep each reservoir is, but he knows the area for the first (120 m²) and for the second (72 m²). F10 had his reservoir dug by the town hall around 2006-2007, having an area of 300 m² and unknown depth. F11's two reservoirs were built 15 years apart, the first in 1989, fed by a spring, and measuring 600 m² and the newest in 2004, of unknown measure. F13's reservoirs precede his ownership of the farm, but he expanded both after 2014 in response of the drought. One of them now have an 1800-m³ capacity.

Concerning the dams, F1 had more built in 2018 because of the drought. The same reason directed F2 to increase his number of dams.

Springs (*nascente*) are the main source of water for farmers in the region, especially those who do not have access to creeks and rivers. They often run underground, close to the surface, and can occur at any point inside the property. Exploited springs sometimes are close to the farmhouse (F6), to the pasture (F7, F12, F13) or to the cattle pens (F8), either coupled with reservoirs (F6, F7, F8, F13), or not (F12). The area around the spring can be protected (F2, F4, F5, F8, F10, F11) or not (F6, F7, F12, F13). The protection is achieved by fencing an area of 0.5 hectare around the spring, as per guidance of the Rio Rural program.

Artesian wells, of all the water sources, are the most closely related to the drought and its effects. With the exception of F6, where it was built in 1999, all the others were dug to offset the effects of the 2014's (F4) or the 2017's drought (F7, F10, F11, F12, F13). The specific purpose for each well differed between farmers. For some (F7, F10, F11), the objective was domestic consumption. For others, it was to alleviate the depletion of reservoirs (F4), in answer to lower spring level (F12) or the result of long-term planning for the dry season (F13). The depth of each well depended on the property, ranging from 7 m (F7, F12) to 15 m (F6).

If water sources represent the supply of water in any given farm, the irrigation is one of the main components of demand for water in the farms. In **Table 10** – , it is possible to see the presence of irrigation system, the area it covers, if it is currently in use, the frequency of usage, the type of system, the specific water source it uses and, finally, the crop being irrigated.

Table 10 – Irrigation system characteristics for each farmer

Farm	Presence	Area (ha)	Current status	Frequency	Type	Water source	Target
F1	Yes	NA	Off	Daily	Sprinkler	NA	Paddocks
F2	Yes	NA	On	Often	Surface	Reservoir	NA
F3	Yes	NA	Off	NA	NA	NA	NA
F4	Yes	2.8	On	Daily	Sprinkler	Reservoir	Paddocks
F5	Yes	3	Off	Often	Sprinkler	Reservoir	Paddocks, grass
F6	Yes	0.01	On	Daily	Surface	Reservoir	Pasture, grass and sugarcane
F7	No	[redacted]					
F8	No						
F9	Yes	≈1	Off	Dry season	Sprinkler	Reservoir	Forage grass
F10	Yes	0.675	Off	Weekly	Sprinkler	NA	Paddocks
F11	Yes	≈1	On	Dry season	Sprinkler	NA	Forage grass
F12	Yes	0.4	On	As needed	NA	NA	Paddocks
F13	Yes	4.2	On	Daily	Sprinkler	Reservoir	Paddocks

It is worth noticing most farmers have irrigation systems installed, although nearly half, five out of eleven, of those who have it are not currently using it. The drought and the general slow recovery of water sources in some locations is main cause identified by owners for the current absence of irrigation. Of all the farmers who stated that they possess irrigation systems, F3 is the only one that admitted to have abandoned it, keeping it around only in case of necessity. Water sources, when stated, always come from reservoirs.

The area of irrigation is an estimation from the area of paddocks and/or grass in most cases, if those areas were known, except for F4, F6 and F11, where the farmers themselves provided the information. It is possible the irrigation area is bigger than stated, as sugarcane and corn, when cultivated, were not accounted into the estimates.

Frequency is a measure of the regularity of irrigation in the farms, currently or when those systems were last active. It is highly correlated with the usage of urea in the pasture, reason why it was possible to infer its value when pasture management practices were known. Values were thus inferred for F1, F2, F4, F5 and F13, as they are farmers who regularly use urea in their paddocks and therefore require constant irrigation. In that group, the difference between those labeled "often" and those labeled "daily" lies in the degree of discipline when applying urea to the fields. F1, F4 and F13 were deemed rigorous in their usage, while F2 and F5 were more flexible in its application. For farmers who stated their irrigation frequency, F9 and F11 merely answered their systems are active only during the dry season. F12 stated that he used to irrigate weekly, but now only does it when needed.

Of the identified irrigation systems, the most common is the sprinkler type, followed by a couple of surface types. Fixed sprinklers are inferred to occur in F1, F4, F5 and F13, as farmers mentioned installation dates and, in one case (F5), costs. F11 has a very specific use for his system, and does not elaborate further on the type of sprinklers used. F10 is a special case, in that he manually sets the sprinklers two paddocks at the time. For surface systems, F2 is the most complete, consisting of two high reservoirs built on top of hills and a 400 m of 2.54 cm diameter tube to conduct the water to his crops/pasture. F6 also uses a surface system, but his is based in a pump and a high-caliber tube that spreads water over a small area, not reaching the entirety of the pasture and crops.

Irrigation is mostly focused on the paddocks, when present, where lactating and highly productive dairy cows graze daily. That is the case for F1, F4, F5, F10, F12 and F13. When there is the presence of *capineira*, i.e. forage grass, irrigation can also cover their area, as is the case of F5 and F6. There are two cases where the *capineira* is the sole focus of irrigation, namely, F9 and F11. It is unknown if sugarcane is irrigated in other properties beyond F6.

7.2.1 Soil-related Ecosystem Services

The results of the indirect assessments are summarized in **Table 11**. The vast majority of farmers who have answered the question do not see a loss of pasture productivity, or grass productivity (F9), over the years, with the single exception of F11. Indeed, F11 is the single medium-sized producer who does make constant use of fertilizer nitrogen (urea). Other non-users are very small-scale producers (F7 and F8) and F3. Interestingly, F11 is also the only farmer who has perceived erosional processes in his property, who admitted to have patches of uncovered soil and who claimed to have overgrazed his pastures, especially during the drought. Every other producer denied the presence of erosion and overgrazing and claimed full soil coverage.

Table 11 – Perceived ecosystem services status by farmers

Farm	Productivity loss	Fertilizers	Erosion	Soil conservation	Soil cover	Overgrazing
F1	NA	Yes	No	Yes	Yes	No
F2	NA	Yes	No	NA	Yes	No
F3	NA	Yes (org.)	No	Yes	Yes	No
F4	No	Yes	No	Yes	Yes	No
F5	No	Yes	No	No	Yes	No
F6	No	Yes	No	No	Yes	No
F7	No	No	No	No	Yes	No
F8	No	No	No	No	Yes	No
F9	No	Yes (org.)	No	Yes	Yes	No
F10	No	Yes	No	Yes	Yes	No
F11	Yes	No	Yes	No	No	Yes
F12	No	Yes	No	No	Yes	No
F13	No	Yes	No	No	Yes	No

Org. = organic fertilizer e.g. manure

That can be contrasted with observations in each visited property, seen in **Table 12**, where evidence of sheet erosion was seen in at least six properties, two of them already with signs of gully erosion (F2 and F11). Observed erosional processes are limited to the hillsides, often following the path of cattle going up and down the hills. Indeed, all farmers who have pasture-based systems leave the hills to cattle not producing milk. The tended pastures are left to milk-producing cows, and the feeding of the rest of the stock is not usually managed. Two farmers

(F6, F7) denied significant hillside grazing in their properties. F6 stated most of his lands are flat, therefore the effect of cattle on the hills are negligible, although observation shows the existence of low hills in his land. F7, on the other hand, mentioned the hillsides in his property are covered in bushes, creating an impediment for cattle to climb the hills, which was confirmed by observation.

Observed data on **Table 12** paint a more nuanced view of soil cover than can be glanced from the interviews alone. Six properties were observed with full soil cover, five with partial cover on the hills and only one with partial coverage on lowlands and hillsides.

Table 12 – Observed ecosystem services in each farm

Farm	Erosion	Soil conservation	Soil cover	Hillside grazing
F1	Yes	Yes	Partial (hills)	Yes
F2	Yes	Yes	Partial (hills)	Yes
F3	Unk.	Unk.	Unk.	Unk.
F4	No	Yes	Full	Yes
F5	Yes	Yes	Partial	Yes
F6	No	Yes	Full	Yes
F7	No	No	Full	No
F8	No	No	Full	Yes
F9	No	Yes	Full	N/A
F10	No	Yes	Full	Yes
F11	Yes	No	Partial (hills)	Yes
F12	Yes	Yes	Partial (hills)	Yes
F13	Yes	Yes	Partial (hills)	Yes

Five interviewees openly declared to have some sort of soil conservation practices. Mostly, by keeping pasture above a certain height (F1, F3, and F10), controlling stock density (F1, F3, and F10) and applying mulching (F3, and F9). Even farmers who have not admitted explicitly to soil conservation practices also perform them as part of their normal management of pastures. Controlling stock density and keeping pasture at a certain height are integral parts to the paddock technique, therefore farmers who use it (F2, F4, F5, F6, F12, and F13), even if partially (F6), are indirectly conserving the soil, although only in the paddock area. There are no efforts to protect the hillsides, with the possible exception of F13, where a new project to introduce a system of paddocks there could give time for pastures to recover.

In order to understand further the dynamics of land degradation in the region, different stock densities were calculated for each property, based on total area, used area and productive area, when data was available or could be extrapolated. Those data were summarized in **Table 13**.

Table 13 – Stock density per area (animals/hectare)

Farm	Stock/total area	Stock/used area	Cows/productive area
F1	0.87	Unk.	2.67
F2	0.58	0.72	3.00
F3	1.24	1.38	5.00
F4	2.21	Unk.	13.21
F5	4.44	5.71	7.00
F6	3.10	3.10	17.14
F7	3.10	3.10	1.03
F8	1.70	1.70	1.03
F9	1.24	Unk.	4.5
F10	0.31	0.93	13.33
F11	1.77	3.06	0.58
F12	3.13	3.79	62.50
F13	1.54	17.78	10.89

Stock density average for total area was 1.94 and for used area, excluding unknown values, 4.13. Cow density average per productive area was 12.89. The density of cows per productive area is higher than total stock density, with exception of F7, F8, F9 and F11. The highest cow densities are in F6 and F12, both of whom have relatively small total paddock area. The lowest cow density is found in F11, followed closely by F7 and F8. F13 has the highest stock per used area density, probably revealing an underestimation of the used area in the property.

7.2.2 The drought

The drought had different effects on each farmer, who reacted to them in different ways. **Table 14** summarizes the economic impacts on each property during the period farmers perceived they were most affected by the hazard. Most farmers identify the year of 2017 as the base drought year, although they all recognize a general process of decreasing rainfall starting at 2014, sometimes even before (F3). Some farmers consider the 2014-2017 period as a single drought event (F3, F4, and F11), one consider both years as isolated, important drought events (F13) and one considers the 2014 drought is an ongoing event (F10).

Table 14 – Drought period and economic impacts in each survey property

Farm	Year(s)	Inputs		Milk output	Cattle loss	Cattle reduction
		Increased	Decreased			
F1	2017	Bulky feed, electricity, commercial feed	Urea (0), labor	Slight decrease	No	Yes
F2	2017	-	Concentrates (0)	Decrease	No	Yes
F3	2014-2017	-	Concentrates (0)	Decrease	No	Yes
F4	2014-2017	Electricity, bulky feed	Urea	Slight decrease	No	No
F5	2017	Concentrates (2X)	Fertilizer	Decrease	Yes	Yes
F6	2017	Soybean meal	-	Decrease	Yes	NA
F7	2017	Concentrates	-	Decrease	Yes	NA
F8	2017	Rock salt	-	Decrease	Yes	NA
F9	2017	Concentrates	-	Decrease	No	No
F10	2014-	Concentrates	Urea	-	No	No
F11	2014-2017	Concentrates	-	Decrease	Yes	NA
F12	2017	-	-	-	No	No
F13	2014/2017	Sugarcane, silage	-	NA	No	NA

There has been considerable variation in input usage during the drought, with farmers taking sometimes opposite strategies to cope with the hazardous event. Five farmers counteracted the decrease in pasture quantity and quality with more protein and energy concentrates. One farmer only increased the quantity of protein concentrates (F6). Two others (F2 and F3) went in the opposite direction and stopped giving concentrates to their animals completely.

An increase in irrigation caused higher energy bills for F1 and F4. F9 quickly exhausted his reserves of forage grass and sugarcane, consequently decreasing its usage. In the opposite direction, F13 increased sugarcane and silage up to 50% of the total cattle feed. In four situations the use of fertilizers were decreased or dropped, particularly urea, representing 50% of the interviewed farmers who use that chemical fertilizer.

Only one property out of twelve managed to keep stable production levels of milk during the drought. All the others experienced a decrease, albeit two (F1 and F4) to a lesser degree. Cattle loss occurred in five of the farms, with being trapped in the mud as the most common stated cause of death. Cattle reduction was a strategy to avoid mounting costs during the drought and to provide an alternative source of income. Four interviewees actively adopted such strategy during the worst of the drought, with F3 stating their gradual reduction started even before 2013, predicting more unfavorable weather in the years that would follow. Of the farmers who did not, F4 and F12 did not feel the need to do so and F9 focused on saving his animals under very low productivity settings.

The impact of the drought on water resources was uneven, with some regions suffering extreme water depletion while others fared considerably better. **Table 15** summarizes those effects in each farm.

Table 15 – The state of water resources during the drought year(s) for each farmer

Farm	Year(s)	Water resources					Irrig. system
		Creek	Reservoir	Spring	Artesian well	Weir	
F1	2017	Dried (3X)	N/A	Dried	N/A	Dried	Off
F2	2017	NA	NA	-	N/A	NA	NA
F3	2014-2017	NA	N/A	N/A	N/A	Sufficient	Off
F4	2014-2017	N/A	Insufficient	?	To reservoir (50%)	N/A	On
F5	2017	N/A	Dried	Dried	N/A	N/A	Off
F6	2017	Lowered	Lowered	Lowered	-	N/A	On ↑
F7	2017	Dried	Dried	Lowered	Lowered	N/A	N/A
F8	2017	Lowered	Lowered	Lowered	Lowered	N/A	N/A
F9	2017	Dried	Dried	Dried	N/A	N/A	Off
F10	2014-	Dried	Dried	Dried	Built	N/A	Off
F11	2014-2017	N/A	Lowered	Lowered	Built	N/A	N/A
F12	2017	N/A	Lowered	-	-	N/A	On
F13	2014/2017	N/A	Lowered	Lowered	Built	N/A	On

Some farmers' water resources were particularly hit by the drought. F1, F5, F9 and F10 had all their sources depleted during that period, with the creek crossing F1's property drying thrice in a year. Under those circumstances, it is logical their irrigation systems were deactivated, and such fact was clearly stated by the interviewees. Two farmers had water resources barely affected by the drought (F2, F12), although only one kept his production levels high during the period (F12). It is interesting to note that both farmers affirmed their neighbors fared much worse in terms of water availability.

All former participants of Balde Cheio's program (F4, F12, and F13) kept their irrigation systems operational during the drought, with two of them (F4 and F13) nearly expending their entire water reserves in the process. F4 dug an artesian well in 2014 to supply his failing reservoirs, managing to fulfill 50% of his water demand. F6 increased irrigation to keep with the increasingly dry weather.

A summary of the perceived effects of the drought on soil is in **Table 16**. The drying of the pastures is an expected result, and in line with water availability in each farm. The only farmer who managed to maintain his pastures preserved was F12, which is in line with his being one of the few who had sufficient water resources and maintained irrigation during the entire period.

Table 16 – Perceived effects on soil and animal health during the drought

Farm	Year(s)	Pasture status	Pasture loss	Soil status	Erosion	Animal health
F1	2017	Dried	NA	Exposed	No	NA
F2	2017	Dried	NA	Covered	No	Good
F3	2014-2017	NA	NA	Covered	No	NA
F4	2014-2017	Dried	NA	NA	No	NA
F5	2017	Dried	Yes	NA	No	NA
F6	2017	Dried	Yes (60%)	Exposed	No	NA
F7	2017	Dried	NA	NA	No	Poor
F8	2017	Dried	NA	Covered	No	Poor
F9	2017	Dried	NA	Covered	No	Poor
F10	2014-	Dried	NA	Covered	No	NA
F11	2014-2017	Dried	Yes (40%)	Exposed	Yes	Poor
F12	2017	Preserved	No	Covered	No	Good
F13	2014/2017	Dried	NA	Covered	NA	NA

Dried pastures did not necessarily correlate with increased soil exposure. Only two interviewees admitted to having exposed soil during the drought, mostly because of cattle eating the grass almost to the root. It can be inferred F6's soil was also partly exposed, as that farmer admitted to 60% pasture loss during the drought. F11 also admitted to pasture loss, around 40%, and so did F5, although he did not estimate his losses. F12 did not lose any pasture, which is line with previously gleaned information.

Despite experiencing pasture loss and exposed soils, farmers' impressions on erosion did not change during the drought. Only F11 admitted to increased erosion, while all the others denied the problem.

Of the few farmers who mentioned animal health during the drought, most admitted the cattle fared poorly, even with an increase in concentrates given. A surprising result is from F2, who emphasized his cattle remained "beautiful", even if as he stopped giving concentrates and only fed them with forage grass and salt in the pens.

To weather the drought, nearly all farmers had to adopt coping strategies, which often focused on finding water and expending sugarcane. A summary of those strategies can be seen in **Table 17**, which also reveals if farmers received outside assistance from the public authorities or neighbors during the drought period.

Table 17 – Coping strategies adopted during the drought year(s)

Farm	Year(s)	Coping strategies			Outside assistance
		Water	Sugarcane	Others	
F1	2017	1-2 trucks/week (4 months)	1 truck (15-16t)/week	Extra feed (8% total cost increase), sold animals	No
F2	2017			Worked for third parties; sold cows	No
F3	2014-2017		Own	Reduced stock, concentrates & production	No
F4	2014-2017	Artesian well (2014)	2-3 trucks/year (2014-2016)		No
F5	2017		Own	Extra feed (75t barley; 2017); urea in feed	No
F6	2017		Own	Napier forage grass	No
F7	2017		Own	No tending the pasture, decreased milking	No
F8	2017				No
F9	2017	Found a well	Exhausted Gifted (Neighbors)	Grass from road margins, banana trees, gifted grass (mutual help)	Yes
F10	2014-	Artesian well	Exhausted	Banana trees, sold calves	Yes

F11	2014-2017	Artesian well	Expanded area 3-4 trucks (2017; 12.5t)	Collected feed around with the help of a truck	No
F12	2017		Sep.-Oct. (2017-2018)		No
F13	2014/2017	Artesian well (2017)	Exhausted	Kept irrigation, increased feeding	No

Dwindling water resources forced some of the farmers to search for alternatives during the peak of the drought. F1 asked for weekly water trucks for nearly four months in 2017, while others dug artesian wells for household use (F10, F11) or production use (F4, F13). Interesting to note F13's artesian well was an adaptation planned after 2014's drought, preceding 2017's drought by a couple of months. F9 did not specify what type of well he found or where.

Sugarcane is the main dry season crop used by dairy farms in the region and its supply was sorely tested during the drought period. All farmers, except F8, had their own supplies and in some, they were stretched to the point of exhaustion (F1, F3, F4, F9, F10, F11, and F13). Of those, a few (F1, F4 and F11) were forced to buy truckloads from the municipality of Campos dos Goytacazes.

Beyond water and sugarcane, farmers' adopted a series of coping strategies to suit their own particular situations. One of the most common solutions was to expend forage grass, also a dry season supplementary crop, present in the properties. Once those supplies were exhausted alternative feeds such as banana trees would be used (F9, F10) or farmers would procure grass from public areas (F9, F11). In one situation (F9), the farmer entered mutual help networks composed of neighboring farmers, who would share feed amongst themselves. A couple of farmers (F1, F5) would buy truckloads of extra bulky feed from other areas.

Another common strategy was winding down the production, either by reactive semi-abandonment (F2, F7) or by design (F3). F2 dropped the production considerably, started working for third parties and sold cows to complement his lowered income. F7 did not see much of a point in tending the pastures or keeping a high production, leaving the milk mostly to the calves. F3 noticed early the signs of the drought and started a deliberate and slow downsizing operation to reduce costs and inputs, thus reducing his losses.

A unique strategy amongst this group was taken by F13, who in 2017 maintained irrigation to keep his pasture alive and primed for recovery with the first rains. They made an effort to increase the feed available in the pens, using sugarcane and silage, to prevent overgrazing of the already weakened grass.

7.3 POST-DROUGHT OUTCOMES

Water levels for each resource at the date of the interviews (2019) can be found in **Table 18**. F5 still has two completely dry springs. F6 considers his general water level 90% recovered. F7's springs recover during the rainy season, but they dry again during the dry season. F8's reservoirs are half-full and nearly full, but the farmer states they are drying fast when there is no rain. F10 claims his water resources improved slightly in 2018, but there is still no water for irrigation. F13's water resources are still not fully recovered.

Table 18 – Status of water resources after the drought year(s)

Farm	Water resources				Rainfall
	Creek	Reservoir	Spring	Weir	
F1	NA	N/A	NA	NA	Good
F2	NA	NA	NA	NA	NA
F3	NA	N/A	N/A	NA	NA
F4	N/A	NA	NA	N/A	NA
F5	N/A	Dry	Dry (2)	N/A	Bad
F6	Recovered	Recovered	Recovered	N/A	NA
F7	NA	Recovered	Low	N/A	NA
F8	Low	Mixed	Lowered	N/A	NA
F9	Low	Low	Low	N/A	NA
F10	Low	Low	Low	N/A	NA
F11	N/A	Recovered	Low	N/A	NA
F12	N/A	-	-	N/A	NA
F13	N/A	Recovered	Recovered	N/A	NA

Prevention measures taken or planned are resumed in **Table 19**. The majority of farmers have invested or plan to invest in an expansion of the same mechanisms they have traditionally use to endure the dry season. Expanding water storage is a priority for nearly half of them, with a similar number choosing to expand feed capacity in their properties. The production of silage occurs only in F2, not being a very popular choice probably because the high costs involved in growing and stocking it. Following the strategy used during the drought, F11 expanded his paddocks into the hillsides, in order to have extra pasture to feed his animals when productivity drops in the dry season. It is unsurprising F3 and F12 have no plans for adaptations, considering the self-described success of the coping strategy of the former and the absence of negative effects of the drought of the latter. That F7 and F8 also have no plans to safeguard their production—the artesian well is for household consumption—is also understandable considering the rather passive strategy both took during the last drought. F10 is mostly retired and has no interest in investing any further in the business.

Table 19 – Preventive measures taken or planned for the next drought

Farm	Planned	Underway/Completed
F1	-	New reservoir; weir
F2	-	New reservoir; silage
F3	-	-
F4	-	Increased sugarcane area
F5	Artesian well	-
F6	Sprinklers	New reservoir
F7	Artesian well	-
F8	-	-
F9	-	Increased grass fodder area
F10	-	-
F11	-	Increased grass fodder area; reduced production
F12	-	-
F13	-	Paddocks on hillsides

8 UNCERTAINTIES AND LIMITATIONS

The results presented show the many uncertainties and limitations of this work. The lack of a consistent methodological framework, in part consequence of the long and incomplete process to precise the research topic, led to flawed interviews that, in turn, cast a shadow over the soundness of the data collected. Caution is thus necessary when analyzing and reviewing them.

The initial research question aimed at valuing the loss of soil-related ecosystem services in the Atlantic Forest. That required three steps: identifying, quantifying and valuing those services. Identification was done *a priori*, with soil cover and erosion chosen as regulating services and milk yield chosen as a provisioning service. Since ES is not a stock, but a flow, they are usually measured by change in time intervals, usually years. Therefore, the change in the provisioning of those ES would need a temporal mark and considering the absence of bookkeeping in the region, a recent drought would facilitate the recall of ES values before and after it. The total ES value would thus be the difference between the quantity times the price of those services before and after the drought, discounting the adaptation and coping costs.

The numerous issues with that approach became evident during and after fieldwork. It was impossible to ascertain independently the degree of land degradation before the drought and observations were limited to the interview area. Furthermore, degradation was verified only in binary terms, presence or absence, for the two variables, diminishing its utility in quantification attempts. It was also clear the vast majority of the interviewed farmers did not recognize any form of land degradation inside their property, which rendered the initial hypothesis of a linkage between degradation and drought effects moot.

Once unable to measure a change in regulating services, the valuation would then depend solely on provisioning services. Under a simple assumption that the state of ES is directly correlated to milk yield, a smaller drop in yield during the drought would mean better preserved ES. However, farmer outcomes varied wildly, and in the impossibility to ascribe specific services to each of those outcomes, the plain variation in yields is of little relevance. To overcome that issue, the productivity change method (PCM) recommends taking data on production inputs, in order to isolate further the impact of ES on outputs.

Input data was indeed collected, but it soon became clear that, even in the case of a complete dataset, it would have limited use. In fact, there was considerable variation in input use and type among farmers, a factor compounded by variations in management techniques, local conditions and coping strategies that could mask even further their effects on yield.

Therefore, even under the best possible data collection conditions, a model as proposed would be of little utility, aggregating a series of inaccurate assumptions into an oversimplifying model incapable of fully encompassing the phenomena it pretends to study. Alas, as it happens, those conditions were far from perfect, resulting in a final dataset affected by researcher-induced and source-induced errors.

Concerning the first error set, it must be said the researcher had no previous training nor experience in designing and conducting interviews, which explains the rather *ad hoc* process described in the Methodology chapter. Surveys were elaborated without proofing or pilot studies, and their focus was on answering a research question that, once the fieldwork was finished, proved to be misguided. The decision now to follow the order of questions proved to be a double-edged sword. While it indeed allowed for greater fluidity and less repetition during the interview, it also created difficulties in keeping track of the topics covered, favoring data gaps and imprecisions. Contributing to those gaps, the interviewer considered no-answers evidence of sensitive or irrelevant topics, and instead of rewording or pursuing that line of inquire, it was abandoned.

Source-induced errors arise from the interaction between interviewer and interviewee during the course of the survey. They relate to recall failure, contradictory or false statements, incomprehension or misapprehension of questions, subject bias towards certain topics, among others. Of those, the inability to remember specific information was the most widespread, especially for numerical variables, of which farmers could only consistently remember milk yield, as it is closely related to their earnings. Quantity and cost of inputs, on the other hand, were often misremembered or forgotten for the years prior to the interview.

Contradictions were common with measurements and dates, as they were often the result of impromptu calculations. The answers to questions regarding soil cover and erosion have shown a degree of defensiveness or at least misapprehension. Bias is no doubt involved in denying the reception of outside assistance during the drought, when in fact many were succored by EMATER's emergency plans between 2013 and 2017.

The unreliability of the dataset was ill suited for an ES valuation, but in a more subjective context, it could be used for a more descriptive study. Regardless, many of the limitations remain in force and, in hindsight, the choice of a theoretical framework explicitly designed for socio-ecological agroecosystems, examples being the Framework for Ecosystem Services Provision (Rounsevell, Dawson, & Harrison, 2010) or Livelisystems (Dorward, 2014), would have solved many of the conceptual inconsistencies in the current work. The unfortunate truth is that wisdom always arrive at the end of the journey.

9 DISCUSSION

This research is based on impressions, both by farmers, expressed in the interviews, and by the researcher, expressed in field observations. The results are thus a sum of those impressions, an attempt to impose order into an array of oft-confusing, complex subjective data. However, using the same approach in the current section would be too stifling and counterproductive, impeding the use of uncategorisable observations and thus limiting the richness of the analysis. Therefore, a choice was made to embrace subjectivity and allow for a more free-flowing discussion of results, one that would take full advantage of interviews and observations.

9.1 ECOLOGICAL OUTCOMES

It is useful to start, then, with an impression, one that coalesced after several dozens of hours of interviews, talks, visits and drives in and around the municipality of Santo Antônio de Pádua. That impression adds nuance to the usually bleak description of Southeast Brazil's pastures in the Atlantic Forest that emerged in recent papers (Hebner *et al*., 2018; Sattler *et al*., 2018; Soares da Silva *et al*., 2018). It is as follows: dairy farming might not be one of the main contributors to the high levels of pasture and land degradation seen in the region.

To understand that impression, we must start comparing the results on soil cover, conservation practices and productivity loss perceived by farmers and observed by the researcher (**Table 11** and **Table 12**). Farmers' painted a rosy picture of the ecological conditions of their lands, a finding that Hitoe Mergner (2018) also highlighted in the region. Observed data show a different picture, but those differences, at least when it comes to soil cover and erosion, have one remarkable consistency: they mostly occur on hillsides.

Hillsides are, coincidentally, where farmers would leave non-productive cattle to roam free. The movement of cattle up and down the hills is often linked to a loss of vegetation cover, soil compaction and subsequent erosion in the region, especially under conditions of overgrazing (Hebner *et al*., 2018; Sattler *et al*., 2018). It is debatable, however, if such conditions are occurring in those affected properties.

The very concept of overgrazing is poorly defined and used inconsistently in the literature (van Oudenhoven, Veerkamp, Alkemade, & Leemans, 2015), making it difficult to apply in specific cases. More enlightening would be a comparison between stocking rates and carrying capacity, but such calculation exceeds the scope of this work.

In its absence, the only data from which to take conclusions are farmers' own opinion, an overwhelming denial, and the ratio of stock per used area. The latter measure is arguably more useful, but only if an equal carrying capacity is assumed for all properties and if paddock use, which would decrease densities for non-productive cattle, is ignored. Nevertheless, the ratios of affected farms are no different from the ones not affected; showing that, perhaps, overgrazing, defined simply as the relative ratio of stock per used area, on itself has little explanatory value.

If overgrazing alone cannot explain the differences seen, then elucidation must come from elsewhere. Topography offer one route of inquiry, with more rugged terrain composed of sloped and taller hills being potentially more sensitive to the movements of cattle. The system of management could also prove instructive to finding an answer.

Concerning topography, the topic was broached only indirectly in the interviews, as part of inquiring the used area. Lowland areas were more than once mentioned as desirable, while hilly areas were deemed detrimental to production. Farmers would always have a mix of both, nonetheless, with dairy cows being concentrated on the lower parts of the property whenever that was deemed possible. From those inquires alone, is not possible, however, to discern any evidence from the degree of roughness of each one's terrains. In a similar way, observations could not resolve changes in relief from one farm to the next, although from the interview area and surroundings some properties appeared particularly steep, e.g. F11 (Figure *6*) and F10.

While topography was a chance topic in the interviews, farm management was at their center. From that exhaustive exposition on production variables, it was possible to identify three management systems based on the technical level applied. Each system has common characteristics that could have differentiated the impact of the drought between them. Mainly amongst those characteristics are urea fertilization, pasture irrigation, paddock subdivision and technical assistance. Traditional systems, in which all of those are absent, were expected to have the highest degree of pasture degradation, seen as a loss of soil coverage, erosion and loss of productivity. Mixed and technical systems would have had the lowest degree, respectively.

It is fair to justify those assumptions. Under post-drought conditions, systems with working irrigation, urea fertilization and paddock enclosures were observed with abundant and verdant pasture in comparison to systems without. The widespread adoption of those techniques since their alleged introduction in 2005 also show local farmers believe them to be advantageous. Furthermore, systems that enlisted the aid of a technician were thriving, and not merely surviving.

Figure 6 – A panoramic view of one of F11's properties

The package of paddocks, irrigation and urea fertilization correspond only to a small portion of the total used area (**Table 10**). That small area, however, is the core of dairy farming, holding and feeding all lactating cows. Assuming that in a highly productive system 75% of the cows should be lactating at any given time, only 25% would join the rest of the herd outside paddock area. The rest of the herd can vary in size, but for the interviewed farmers, it was usually equal to the number of cows for farmers who had no beef cattle. That means a relatively small number of animals would roam the hillsides, where no paddocks, irrigation or fertilization were applied.

Indeed, hillsides are still managed in the traditional way, regardless of the system. Only farmers with limited lowland area take the paddocks up the hills (F3, F5), but again, the ratio of used to irrigated area seems to indicate potential free-range area would still vastly exceed total paddock area (**Table 10** and **Table 13**). The relatively laissez-faire attitude towards hills also mean soil conservation techniques are less likely to be enforced. It is doubtful farmers who leave longer grass stalks for mulching or take care in leaving the grass at a certain height spend time and effort applying those to assumedly less productive areas.

That does not mean hills are completely unmanaged. Trimmed and weeded hills are both a sign of prosperity and an aesthetic ideal. The growth of secondary forests on hilltops represents, on the other hand, the abandonment into which, if observations of roadside properties are representative, the region is slowly falling. Beyond the symbolic nature, staving off the growth of trees and weeds has practical sides, as it maintains pasture dominance and keep areas open for grazing. Usually, weeding and trimming is a yearly task accomplished with the aid of hired laborers, which explains why the current labor shortage in rural areas has decreased that practice amongst less fortunate farmers.

Truly, very few of the observed farms had fully trimmed hill pastures. Even relatively wealthy farmers such as F1 had visible secondary forests growing on hilltops overlooking the milking parlor (Figure *7*). Yet, an effort is made to maintain the hillsides free of shrubs and weeds.

The digression into hill management is of fundamental importance to understand socio-ecological components of erosion in the region. As seen, hillsides are the most affected by erosion and the kind of management the favors uniform short grass covers and free-range cattle are its main causes. Once that is understood, cattle stocking rates and landscape relief become useful in explaining different outcomes. Indeed, those factors might explain why some farms had full soil cover and no signs of erosion while others were considerably more scarred. The lack of data on those two variables is unfortunate, meaning that they cannot be tested for the individual farm outcomes.

If erosion and patches of soil cover loss are concentrated on hillsides and that is a consequence of management, then it follows that under a different management such impacts could be prevented. Instead of being an afterthought, non-productive cattle could be enclosed in lowland paddocks, therefore negating the impact on hillsides. Even tended paddocks on the hills could maintain soil cover and reduce erosion. The ability to implement such techniques are well within the possibilities of local farmers, especially those with mixed and technical systems.

Figure 7 – Erosion marks during the wet season in F1's property viewed from the holding pens.

The drought also affected the supply of ecosystem services in the region. However, interviews only revealed its effects on two services explicitly—milk yields and water for agricultural uses—and one implicitly—pasture productivity. It is possible the drought also increased soil cover loss and erosion during the period, but without observations, only farmer answers are available, and those are no different from the ones given for the period in which the interview was made (post-drought); therefore, they will not be considered in the discussion.

Pasture productivity, defined as the amount of dry mass per hectare, is not systematically measured by farmers. They perceive it as the maintenance of pasture vigor over the years under grazing conditions. It is interesting that when asked about pasture productivity losses over the years, only one farmer noticed it, with all the others denying its existence. However, when asked about the status of the pasture during the worst of 2017's drought, most stated their pastures dried or died. That indicates a stage beyond the initial effects of a water deficit, which can manifest itself in forage grass as slower leaf area and root growth, a smaller number of shoots and decreased flowering (Cavalcante, Cavallini, & de Barros Lima, 2009; Ugherughe, 1986).

Fertilization and irrigation are closely related to pasture productivity. For instance, Euclides *et al*. (2010) noticed that in Brazil phosphorous shortages limit pasture establishment and sustainability, while nitrogen deficiency hampers pasture productivity. Rocha Junior *et al*. (2017) found that fertilized soils have greater plant aerial and root biomass compared to other management types. Irrigation, according to Corrêa & Santos (2006), helps in the accumulation of pasture dry matter, especially during the dry season and under high temperatures. The combination of fertilization and irrigation could then have permitted for a higher pasture productivity, i.e. more preserved pasture, during the drought than what was reported by farmers.

The most likely reason for that disparity lies in the rapid decline in water resources experienced by the majority of farmers. Indeed, water for agricultural uses was severely limited during the drought, which made irrigation impossible after a certain point (**Table 15**). Up to that point, though, it could have aided in staving-off pasture death.

Reduction in the supply of water for agricultural use, reflected in the status of water resources (**Table 15**), was the main driver of changes in the provision of other ecosystem services during the drought. Water shortages led to pasture death, limiting forage availability and dropping milk yields. Additionally, water access became increasingly difficult for animals, with drying reservoirs turning into death traps if animals were left unattended. As the drought advanced into spring and temperatures started to rise, animal comfort and milk yields would decrease even further.

The level of water shortages was uneven amongst farmers. Some experienced only light shortages, while others were forced to face severe water scarcity situations. Reasons for those distinct scenarios are complex, potentially involving topographic, geomorphologic and microclimatic variables, the majority of which are beyond the control of individual landowners and outside the scope of this work. However, farmers can influence how resources are used and conserved, and that is done building storage capacity (reservoirs and weirs), drilling underground water (artesian wells), fencing springheads, protecting recharge areas, and so on.

Of particular interest is the protection of springheads by fencing, a program spearheaded by the municipal branches of EMATER. The program aims to increase compliance to the new Forest Code (Law no. 12651/12), which established a legal obligation for a protected area with a minimum 15 m of radius around each springhead in rural properties. Amilton *et al*. (2013) lists many potential advantages of forest cover around springs, which include maintenance of water table level and a degree of water scarcity protection during the dry season. Nonetheless, the results show the presence of fenced springs, even those taken by secondary forest, did not seem to affect farmers' water supply during the drought.

In fact, several of the worst hit farmers did have their springheads fenced for at least 3 years before the drought (F5, F10, and F11), while farmers with no protection whatsoever claimed to have had enough water for the whole period (F6 and F12). It could be that secondary vegetation attenuated the effects of the drought in the beginning, but as the situation of water scarcity went on into the warm season, higher transpiration rates would increase water competition and absorption by trees and shrubs, leading to a faster depletion rate of the springs. That is a hypothesis that could be investigated in further studies.

Milk yields, as seen, are highly dependent on pasture productivity and water for agricultural use supplies. Considering both services were negatively affected by the drought, it is logical milk output would decrease as well. The results show exactly that, with two exceptions. The first, F10, is hard to explain, considering the farmer faced severe water and fodder scarcity conditions in 2017. It possible his earlier investments in high yield cattle breeds paid off by maintaining high yield in an adverse environment. F12's case is relatively straightforward: the farmer was only lightly affected by drought, managing then to keep improving his yield.

Farmers with mixed systems suffered a similar drop in production compared to traditional systems, which may be related how the water shortages eliminated two of the main advantages of the former, namely irrigation and fertilization, as the drought advanced on the region.

It is uncertain how forage and concentrate complementation affected milk yields during the drought. Farms that had their sugarcane and grass fodder supplies exhausted before the beginning of the rains fared better than those that had not, although in at least three occasions (F1, F4 and F11) that shortage was covered by shipping in sugarcane from distant municipalities. The effects of concentrates are even less clear, as lower yields occurred independently of their raising or decreasing usage. Farms that lowered or eliminated concentrate (F2 and F3) use also changed their *modus operandi* in drastic ways, e.g. reducing cattle stocks and keeping production at survival level, making the comparison with those who increased its use difficult.

9.2 ADAPTIVE AND COPING STRATEGIES AND THEIR COSTS

Dairy farmers in the region are no strangers to seasonal variations in rainfall. Over time, they have developed a number of adaptations to reduce the impact of the dry season over their production systems, the foremost amongst them being sugarcane/grass fodder reserves and water storage units. It is no wonder those two adaptations also conformed the backbone of defense against the drought in nearly all properties. Most coping strategies were designed around the use or were a consequence of the exhaustion of those resources.

Fodder reserves exhaustion, for instance, led farmers to procure alternative sources of feed. Some, mostly those with sufficient financial funds (F1, F4 and F11), would buy sugarcane in the market, while others would scavenge their properties and public areas for anything that cattle would eat (F9, F10, and F11). It is clear from the prices paid by each truckload of sugarcane, around R$1500-2000, that frequent buyers incurred in substantial extra production costs. On the other hand, scavenging was labor-intensive but, if done without hiring a truck and loaders, had no additional monetary costs.

Water storages were sorely tested during the drought. If water was enough to irrigate the pasture the entire period, farmers adopted little in terms of coping strategies. In the case of low water supplies, strategies varied, with the search of alternative sources far from being a universal strategy. Only a few bothered to open artesian wells, and half of those (F10 and F11) used them exclusively for household needs. Asking for water trucks was not a popular option and it was possible to discern pride in those who answered they did not need those. Indeed, for F1 that was seen as a desperate measure in a situation of total water shortage, where even animals had nothing else to drink.

Dwindling water sources also imposed constraints on irrigation systems. Dynamic farmers (F1, F4 and F13) tried to keep irrigation going as long as possible, but only F13 had sufficient water resources to keep his strategy going uninterrupted. Other farmers had no choice but to stop irrigation and thus urea fertilization altogether. Considering only water demand and the volume in cubic meters of stored water, farms with large reservoirs and modest water demand—here a function of irrigation frequency, volume and area—would have had longer lasting supplies.

However, the size of each reservoir is not known for each farmer, nor the volume of water used for each irrigation. Furthermore, other factors certainly affected the total available water supply in each farmer, as discussed in the previous section. That way, currently it is not possible to draw any conclusions on the comparative effectiveness or sufficiency of water storage for the drought. In spite of that, it is possible to conclude that for most individual farms water supply in general and water storages in particular were insufficient to cover the entire demand during the drought.

Being forced to turn off irrigation created a forage shortage that was initially supplied with dry season fodder cultivated on the own farms. That increase in demand for sugarcane and grass fodder is another reason for the depletion of the supply of fodder. Water, feed and milk production are interconnected in multiple ways in the dairy system, with changes in one variable spreading out to every other, creating an array of stabilizing and destabilizing feedback loops inside the system.

Farmers tried to counteract both forage shortages and a looming fodder shortage in many different ways. A common strategy was increasing the quantity of concentrates, in the belief it would maintain production and/or save the cattle. That such strategy would be applied in some situations with a voluntary decrease in the milk produced is baffling— meant higher costs and lower revenues—and shows the degree of desperation into which some farmers fell. It is ironic that the farmer who did not use concentrates nor any kind of fodder managed to have same or lower percentage drop in production compared to those who did. It is possible the net effect of complementation is negligible for low yielding cattle under drought situations.

Another strategy, used by F5, consisted in adding urea and barley to the feed. The choice of urea as a feed is curious, as it was not emulated by no other interviewee. Indeed, one farmer (F4) even stated that urea is toxic for heifers, thus justifying his not feeding urea-fertilized pasture to them. However, urea as a feed is has been practiced in dairy farming, although not without controversy, for at least one hundred years, as a protein substitute (Kertz, 2010). In Brazil, the use of urea and sugarcane as a feed for dairy cattle is even considered by some authors as widespread (Aroeira, Silveira, Lizieire, Matos, & Figueira, 1993 *as cited by* Pinto, Pereira, & Mizubuti, 2003). Be as it may, F5 did not justify his reasoning for using urea and sugarcane, although it is possible rising prices of soybean meal concentrates may have influenced that decision.

Other notable strategy consisted in downsizing, with a reduction in the number of animals, inputs and production. It could be accidental (F2), resulting from a spontaneous reaction to adverse circumstances, or deliberate (F3), following a plan that predicted a deterioration in the environmental conditions. In their own specific contexts, it can be said both modes of action were successful in cutting costs and keeping intact the remaining capital, which can be seen in the fast rebound in production both farmers experienced the following year (2018). The loss of revenue during the worst period of the drought was covered by cattle sales, working for third parties (F2) and with the remaining milk production.

10 CONCLUSION

The 2014-2017 drought was an external driver that affected soil natural capital by disrupting the normal humidity fluctuation expected for the region. At the scale of individual dairy farms, the drier environmental conditions, especially once extended over the hot season (September-April) was expected to reduce pasture productivity, hence milk yield, and increase production costs, leading to financial hardship and a loss of living standards. However, the research identified a number of different outcomes that lead to a more complex understanding of drought impacts at the micro-scale.

Those outcomes ultimately originate from differences in water supply, water demand, and feed availability, their subsequent change by the drought and farmers' reaction to those changes at each property. When the drought pushed water supply lower than demand, farmers would face a decrease in productivity with a potential loss of capital in animal units unless they increased water supply, reduced water demand and/or used available feed.

An increase in water supply implies acquisition from outside sources or tapping underground sources, both of which require funds and/or labor to be realized. Funds may come from debt, savings and sales, while labor can be hired, donated or owned. Increasing the supply could attend a production goal e.g. refill a reservoir for irrigation, or a subsistence goal e.g. provide water for household use. Farmers reduced water demand by cutting down the number of animals and/or curtailing irrigation. The two were cost-saving measures, although the first option had the additional advantage of generating much-needed cash, albeit at a discounted rate. If a sufficient herd remained by the end of the drought, the population quickly rebounded to previous levels.

The final determinant of outcomes, feed availability, had the largest variation. Supplements (cornmeal, soybean meal, wheat bran) either increased or decreased, which reflected respectively into a rise or fall in production costs, with dubious effects in milk yield. Sugarcane, when available, was used or bought, the second option increasing the costs of production. Pastures, if irrigated, sustained yields for longer, albeit at the cost of urea fertilization. Once the pasture was dry, grazing continued or ceased, with or without complementation with sugarcane, urea, barley or other crop. Continued grazing led to pasture death, compaction and erosion, in case of large herds with no irrigation and zero rotation, or to pasture preservation, in case of smaller herds with irrigation, pasture rotation and heavy sugarcane complementation. Pasture death meant re-planting costs once the drought was over; pasture preservation, on the other hand, avoided those costs.

Complementation likely contributed to maintain animal welfare during the drought, but at an increased cost in farms that exhausted their own supplies before the hazard was over. Supplementation was more often than not increased, with little evidence of gains in yield. Irrigation and fertilization allowed farmers to operate in relative normality as long as water storages held, reducing the time window under the influence of the drought.

The combination of those determinants and the specific pathways taken through their branching components, resulted in the different socio-economic and ecological outcomes perceived for the drought. Every decision carrying an additional cost that was not counterbalanced by additional revenue led to greater financial insecurity. Strategies that relied on grazing dried pasture were accompanied by land degradation if animal density was not controlled and complementary feed was insufficient. The corollary is that soil erosion and soil cover loss did not increase when grazing in dry pasture did not occur or if it occurred in conditions of controlled animal density with sufficient complementary feed, even in vulnerable areas such as hillsides.

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