The impacts of climate changes on agriculture production and adaptative strategies for family farmers in the Brazilian Sertão[1]

Área 11 – Economia Agrícola e do Meio Ambiente

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Resumo

O Sertão brasileiro é a região semiárida mais populosa do mundo e apresenta as maiores taxas de pobreza e insegurança alimentar do Brasil. Chuvas irregulares e instabilidades climáticas tornam o equacionamento desses problemas sociais ainda mais difícil de ser obtido em curto prazo, uma vez que as principais atividades econômicas na região, como a pecuária leiteira e a agricultura de subsistência, tendem a ser especialmente afetadas pela recorrência de secas prolongadas. Este trabalho analisa os impactos de mudanças climáticas na produção agrícola do semiárido da Bahia, o mais populoso estado do Sertão, e como estratégias adaptativas podem atenuar esses efeitos entre produtores familiares. Primeiramente, analisa-se a dinâmica das variáveis climáticas entre 1974 e 2013 na região. Em segundo momento, a partir de modelos para dados em painel, avalia-se os impactos das variáveis climáticas sobre a produção agrícola dos municípios da região. Em terceiro momento, estima-se, a partir de microdados do Censo Agropecuário 2006, a relação entre estratégias adaptativas e a produção de agricultores familiares. O estudo analisa quatro principais tipos de produção agrícola: leite, bovinos, caprinos, ovinos e milho. O objetivo final e geral deste estudo é discutir a eficácia das estratégias para os pequenos agricultores, que sejam capazes de criar resistência ao clima e atenuar os impactos negativos das alterações climáticas na produção agrícola desta região vulnerável socioeconomicamente.

Palavras-chave: economia do meio ambiente, políticas ambientais, desenvolvimento rural, caatinga

Abstract

The Brazilian Sertão is the most populous semiarid region in the world, and faces the highest rates of poverty and food insecurity in Brazil. Irregular rainfall and climate variability make these social constraints even more difficult to be solved in the short term, since basic economic activities in the region, such as dairy farming and subsistence agriculture, tend to be affected mainly by recurrent and prolonged droughts. This study analyzes the impacts of climate conditions on the agricultural production and how adaptative strategies may alleviate such effects. First, it analyzes the dynamics of climate variables between 1974 and 2013 in the semi-arid region of the State of Bahia, the largest and most populous State of the Sertão. Secondly, based on a panel with climatic and production data, it assesses the

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ex-post impacts of these climate variables on the agricultural production of the municipalities in the region. Thirdly, it estimates the relation between several adaptive strategies and the family farmers' production, based on microdata of the Brazilian Agricultural Census for small farmers in the region. The study evaluates four main agricultural productions: milk, cattle, goat, sheep and corn. The final and general aim of this study is to discuss the effectiveness of strategies for small farmers which would create climate resilience and attenuate the negative impacts of climate change on the agricultural production of this vulnerable region.

Keywords: natural resource economics, environmental policy, rural development, caatinga

JEL: Q18, Q51, Q54

1. Introduction

With a population estimated at more than 22 million people in 2010, the Brazilian Sertão is the most populous semiarid region in the world. Despite recent improvements, the region still presents the highest rates of poverty and food insecurity in Brazil. Irregular rainfall and climate variability make these social constraints even more difficult to be solved in the short run, since basic economic activities in the region, such as dairy farming and subsistence agriculture, tend to be affected mainly by the recurrence of prolonged droughts. Studies suggest that the average temperature in *Sertão* increased by approximately 2°C over the past 40 years, while the average precipitation fell between 300 and 450 mm, which corresponds to a reduction of 30% (Burney et al. 2014).

The practice of extensive livestock farming prevails in the region and exposes the animals directly to the natural environmental conditions and, hence, to the impacts of climate changes. Studies suggest that the loss in milk production in the region may vary from 3 to 7 kg/day, depending on the extent of climate changes (Silva et al. 2010). Moreover, according to the most pessimistic forecasts, an increase of almost 6° C in the average temperature would induce a drop in land availability and provoke negative effects on the regional GDP, which could decrease by nearly 14% (Domingues, Magalhaes, and Ruiz 2011; Krol et al. 2001). The agricultural activities would suffer a significant decline, with a reduction of nearly 20% in all states of the region.

In such a relevant environmental, social and economic context, this study has three main objectives. First, it analyzes the dynamics of climate variables between 1974 and 2013 in the semi-arid region of the State of Bahia, the largest and most populous State of the Sertão. Secondly, based on a panel with climatic and production data, it assesses the ex-post impacts of these climate variables on the agricultural production of the municipalities in the region. Thirdly, it estimates the relation between several adaptive strategies and the agricultural family farmers' production, based on microdata of the Brazilian Agricultural Census 2006 for small farmers in the region. The study evaluates five main agricultural productions: milk, cattle, goat, sheep and corn. The final and general aim of this study is to discuss the effectiveness of strategies for small farmers which would create climate resilience and attenuate the negative impacts of climate change on the agricultural production of this vulnerable region.

2. Theoretical background

Climate changes are expected to cause several impacts on the semiarid regions, including water scarcity, increases in average temperature and the frequency of extreme events, such as prolonged droughts (IPCC 2014; Kahil, Dinar, and Albiac 2015). There is also the risk of desertification in some areas, as a result of reduced natural vegetation and increasing degree of soil aridity (Becerril-Pina et al. 2015; Herrera-Pantoja and Hiscock 2015).

In Brazil, the agricultural activity prevailing in semiarid regions is the extensive livestock in family farms, which directly exposes the animals to natural environmental conditions and, consequently, to the impacts of climate changes (Andrade-Montemayor et al. 2011). In addition to high exposition to natural

phenomena, these less developed regions simply lack basic social and economic capital that is needed to adapt to new environmental constraints, such as investments in infrastructure and adaptative strategies (Maharjan and Joshi 2013; Wreford, Moran, and Adger 2010; Mendelsohn and Dinar 2009).

The climatic instability can severely limit livestock productivity in these regions, through, for example, water scarcity, reduction in the provision and quality of pastures and forages, and increasing number of animal deaths associated with prolonged droughts and severe conditions of heat stress (Megersa et al. 2014; Lioubimtseva and Henebry 2009). As a result, climate change may also impact on the farmers' choices for different types of agricultural activity. Kabubo-Mariara (2008), for example, suggests that increasing average temperatures and reducing precipitations tend to make farmers more likely to migrate from dairy to beef cattle, and from goat to sheep farming.

The change toward herds that are naturally more resistant to the extreme climate conditions of the semiarid regions may be a growing trend with climate changes. Larger animals face more difficulties to eliminate the excess of heat, which would reduce their food intake and make them more susceptible to suffer from heat stress (Wreford, Moran, and Adger 2010; Maharjan and Joshi 2013; Mendelsohn and Dinar 2009). Larger animals are also more vulnerable to water and food scarcity compared to smaller animals like goats and sheep.

Several adaptative strategies can also attenuate the impacts of climate changes on the agricultural activities of semiarid regions. According to Wossen et al. (2014), combined strategies of credit and irrigation supply have been effective in reducing poverty rates and the risk associated with climate variability in drought years. Pinheiro (2012) and INSA (2008) also highlight the need of structural changes in farms, such as the confinement and shadding of the livestock, which are essential to minimize production losses, alleviating the negative effects of increases in temperature. Burney et al. (2014) also highlight the potential benefits of irrigation and supplemental feeding of animals. Although both irrigation and food supplementation are cost-effective, they depend severely on the availability of water and infra-structure in the farms. Thus, public and private programs to subsidize the access to water for small farmers are essential, either through groundwater or the construction of dams or tanks.

3. Empirical framework

3.1. Data source

Minimum comparable areas

The impact of climate change on agricultural production is analyzed using the smaller territorial units available in Brazil. Although socio-economic data for 266 municipalities of the Bahia semi-arid region were available, many of them have emancipated in the period of analysis. This means that the total number of municipalities in 1974 does not correspond to that of 2013, neither do their regional boundaries. In order to consider the changes implemented in the Brazilian Territorial Division between 1974 and 2013, the 266 municipalities of Bahia's semiarid region were aggregated into 206 Minimum Comparable Areas (MCAs) according to the methodology proposed by the Brazilian Institute of Geography and Statistics (IBGE) and the Institute of Applied Economic Research (IPEA) (Reis et al. 2011). Each MCA consists of one or more municipalities, historically comparable, i.e., integrated areas of the territory before emancipations realized during the analysis period.

Climate data

Climatic data were obtained from conventional weather stations of the National Meteorological Institute (INMET). These data refer to historical series of climatic variables for the 26 weather stations in Bahia and 4 stations located in the northern region of Minas Gerais, all them located in semi-arid regions. Variables comprise daily data of maximum temperature, minimum temperature, average temperature and

total precipitation between the years 1974 and 2013. However, information for the years 1981-1985 and 1989-1991 were not available.

Daily data were interpolated through the 206 MCAs located in the semiarid region of Bahia. The interpolation was performed by the method of Inverse Distance Weighted (IDW) using the package *gstat* of geostatistical analysis developed by (Pebesma 2004) for the statistical program R. The IDW method is based on the weighted linear combination of the data collected in each meteorological station, using the inverse of the distance as weighting factor (Amorin et al. 2011). After interpolation, the average daily values of climate variables were estimated for each of the MCAs in the region.

The description and average values of the climate variables used in the analyses are shown in Table 1. Overall, results highlight the high levels of average temperatures and the low levels of rainfall, measured by the number of days per year without rain. The average annual temperature varied between 23 °C and 24 °C, while the number of days per year with precipitation lower than 1 mm varied between 232 and 272.

Table 1 – Climate and production variables for the MCA in the semiarid of Bahia

Variable	Description	1974	2013
Climate			
maxtemp	Annual average of the maximum daily temperatures (°C)	28.7	30.4
avgtemp	Annual average of the mean daily temperatures (°C)	22.8	24.3
mintemp	Annual average of the minimum daily temperatures (°C)	18.4	19.3
humidity	Average annual humidity (%)	73.6	68.6
precip	Total annual rainfall (mm)	1093	727
norain	Number of days in the year with rainfall lower than 1 mm (days)	232	272
Production and Population			
prural	Rural population (thousand persons)	3,025	2,684
Pmilk	Milk productivity (liters/cow per year)	388	499
Cattle[1]	Cattle production (thousand heads)	4,653	5,928
Goat[1]	Goat production (thousand heads)	1,646	2,341
Sheep[1]	Sheep production (thousand heads)	1,755	2,615
Corn[2]	Corn production (thousand tonnes)	320	631

Source: INMET and SIDRA (IBGE); [1] Final data refer to 2012; [2] Initial data refer to 2003

Agricultural production

Information of agricultural production and population in the semiarid of Bahia were obtained from the IBGE System of Automatic Recovery (SIDRA) and refer to the following surveys: i) Municipal Livestock Survey (PPM); ii) Demographic Census. This information was originally available to municipalities, that were aggregated into the 206 MCAs. Table 1 describes the variables used in analyses, which were largely limited to the availability of annual information for all semiarid locations. Five types of production and productivity were considered: productivity of milk (variable *pmilk*), cattle (*cattle*), goats (*goat*), sheep (*sheep*) and production of corn (*corn*). Information on milk productivity refers to the period 1974 to 2013. Information on livestock production, goat and sheep refers to the period 1974 to 2012. In turn, information on corn production was available exclusively for the period 2003-2013. Information on rural population (*prural*) was only available for the census years: 1970, 1980, 1991, 2000

and 2010. Values between the census years were estimated based on the average growth rates for each MCA.

Despite the persistence of rural exodus in recent decades, the semiarid of Bahia still has a significant rural population, with 2.6 million residents in 2014. The productivity of milk, one of the main agricultural products in the region, is low: 499 liters per cow in 2013, a value that is substantially below the national average, which was 1492 liters per cow in the same year. Cattle farming prevails in the region (nearly 6 million heads in 2013), although the number of goats and sheep are also significant: 2.3 and 2.6 million heads, respectively. Corn production in the Bahian semiarid (631 thousand tons in 2013) is mainly used for animal feed, and represented 29% of the total state production (less than 1% of the total national production).

Characteristics of small farms

The associations between characteristics of small farmers and agricultural production are analyzed using data of the Agricultural Census 2006 of IBGE. The Agricultural Census allows us to consider a wide range of socioeconomic characteristics of farms as determinants of the agricultural production. Thus, it allows us to establish the relationship between the production and characteristics of farms and the production system, such as the use of strategies to mitigate the impacts of climate change on agricultural production. It also allows a specific analysis for the production of small family farms, since this classification is available in the Agricultural Census. So, despite the fact that the Census allows only a static comparison of farm production under different climatic conditions (only the impacts in 2006), it allows us to evaluate the potential impacts of adaptive measures on agricultural production, such as use of mechanical technology, technical guidance and treatment of soil.

The Agricultural Census contains data for the total population of farms in Brazil. In this analysis, we used the information of family farms in the semiarid region of Bahia, which represented 509,775 establishments in 2006. Family farms were classified according to the variable "*Family Farm*- Law 11326 of 07/24/2006." In addition to information on the value of production, analyses also consider characteristics of the farmer, such as education and membership of a cooperative or agricultural association, and the production system, such as the use of technologies, soil treatment and technical guidance. The list of variables associated with the characteristics of the farms, farmers and the production systems are described in Table 2 and Table 3. All variables refer to the 2005-2006 harvest.

Similarly to the analysis of the municipal production, five types of production were considered in these analyses, identified by the variables *milk*, *cattle*, *goat*, *sheep* and *corn*. Among the small family farmers, cattle and sheep farming also prevail, practiced with a very low level of intensification. The average number of heads of cattle per farm was 6.6, and the average number of heads per hectare of pasture was only 0.8. Similar results are found for sheep and goat, with an average number of heads per farm respectively equal to 2.9 and 3.6 and average number of head per hectare equal to 0.4 in both cases. The average milk yield per family farm is 123 liters per year, which amounts an average yield of 1045 liters per cow (123 liters / 0.12 cows = 1045 liters / cow). This milk yield is higher than that estimated for the whole territory (Table 1), which considers all types of farms and is based on estimates for the municipal production, but it is still significantly below the national average per family farm (1556 liters / cow). In turn, the average corn production per family farm is 1.4 tons.

The farm size (*atotal*) controls the physical capital. In the case of production of cattle, sheep, goats and milk, five types of land use are considered: natural pasture area (*anatpast*), degraded pasture area (*adegpast*), non degraded pasture area (*andegpast*) planted area of forage (*aforage*) and area of forest (*aforest*). The planted area of corn (*acorn*) is used in the corn production. The average farm size is 14 hectares, which is used predominantly for livestock farming. The pasture areas represent more than half the farm size: on average 3.4 hectares of non-degraded pasture, 0.9 of degraded pasture and 3.6 of natural

pasture. Areas of forage (especially palm) adds 0.4 hectare, on average, and forests (savanna) 4.5 more hectares. The average planted area with corn is 1.4 hectares.

Table 2 – Variables related to the characteristics of the farms and farmers in the semiarid of Bahia

Variable	Description	2006
Production and Population		
milk	Dairy production (thousand liters)	123
cattle	Cattle production (heads)	6.58
goat	Goat production (heads)	2.89
sheep	Sheep production (heads)	3.57
corn	Corn production (tonnes)	1.38
Area and inputs		
acorn	Corn area harvest (ha)	1.38
atotal	Total area (ha)	14.25
anatpast	Natural pasture area (ha)	3.44
adegpast	Degraded pasture area (ha)	0.90
andegpast	Not degraded pasture area (ha)	3.56
aforage	Forage area (ha)	0.41
aforest	Forest area (ha)	4.45
cow	Number of cows (heads)	0.12
lf	Total labor force (persons)	2.39
Associativism		
coop	1 if member of cooperativism (0,1)	0.01
assoc	1 if member of a farmer association (0,1)	0.42
Social characteristics		
female	1 if the farmer is a woman (0,1)	0.19
age29	1 if the farmer is 29 years or younger (reference of analysis)	0.07
age30_39	1 if the farmer is between 30 and 39 years (0,1)	0.16
age40_49	1 if the farmer is between 40 and 49 years (0,1)	0.21
age50_59	1 if the farmer is between 50 and 59 years (0,1)	0.22
age60	1 if the farmer is 60 years or older (0,1)	0.34
school00	1 if the farmer is illiterate (reference of analysis)	0.40
school01	1 if ther farmer can read and write (0,1)	0.18
school02	1 if the farmer has adult literacy (0,1)	0.06
school10	1 if the farmer has elementary education with no diploma (0,1)	0.28
school11	1 if the farmer has elementary education with diploma (0,1)	0.04
school21	1 if the farmer has secondary education with diploma (0,1)	0.04
school31	1 if the farmer has a university degree with diploma (0,1)	0.00

Source: Agricultural Census (IBGE)

The labor force is controlled by the variable *lf*, which corresponds to the sum of family labor (including managers) and hired labor. Proxies for social capital are: membership of cooperative (*coop*); or membership of farm association (*assoc*). Farms have, on average, roughly 2 workers, and only 1% of them are members of cooperatives. Participation in farm associations is more usual: 42%.

Human capital and social relations are analyzed by variables related to gender (*female*), age (*age*29, *age*30_39, *age*40_49, *age*50_59, *age*60) and education: no education (reference of analysis); can read and write (*school*01); adult literacy (*school*02); incomplete primary education (*school*10); complete primary education (*school*11); complete technical or secondary education (*school*21); and complete college education (*school*31). Results highlight that farmers are relatively elderly by Brazilian standards, since 34% of farmers are 60 years old or more, and they present very low levels of education, since 40% of the farmers have no formal education.

Table 3 – Variables related to the characteristics of the system of production in the semiarid of Bahia

Variável	Descrição	2006
Technology and assistance		
atraction	1 if farm used animal traction (0,1)	0.386
mtraction	1 if farm used mechanical traction (0,1)	0.273
guidance	1 if farm received technical assistance (0,1)	0.053
Land management		
soilcor	1 if farm used limestone or soil pH correction (0,1)	0.027
fertilizep	1 if farm fertilezed pasture (0,1)	0.017
fertilizec	1 if farm fertilized crops (0,1)	0.190
fallow	1 if farm used fallow, crop or rest to recover pasture (0,1)	0.137
rotation	1 if farm realized pasture rotation (0,1)	0.191
Adaptative measures		
well	1 if farm had a water well (0,1)	0.083
weir	1 if farm had a weir (0,1)	0.152
cistern	1 if farm had a cistern (0,1)	0.247
diseasec	1 if the farm realized control of diseases or parasites in animals (0,1)	0.452
Market and credit		
specialized1	1 if the farm was highly specialized in one product (0,1)	0.203
specialized2	1 if the farm was specialized in one product (0,1)	0.309
specialized3	1 if the farm was not specialized in one product (reference of analysis)	0.488
integrated1	1 if the farm was highly integrated to the market (0,1)	0.190
integrated2	1 if the farm was integrated to the market (0,1)	0.205
integrated3	1 if the farm was not integrated to the market (reference of analysis)	0.605
credit	1 the farm received public credit (0,1)	0.069

Source: Agricultural Census (IBGE)

The use of technologies is analyzed by the variables *atraction* (if the farm uses animal traction) and *mtraction* (if the farm uses mechanical traction). The variable *guidance* indicates whether the farm received technical assistance by qualified professionals. The use of good agricultural practices considers: the fertilization of pastures and crops (*fertilizep* and *fertilizec*); the use of lime or other corrective of soil ph (*soilcor*); the use of fallows, rest or crop to recover pastures (*fallow*); and the use of pasture rotation (*rotation*). The use of animal or mechanical traction is low among family farms in the semiarid of Bahia: 39% used animal and 27% used mechanical traction. The percentage of farms that received some technical guidance in agricultural production is also remarkably low, only 5% in 2006. Technics of soil treatment are also rare: 3% applied lime or other correctives of soil pH, 2% fertilized their pasture and 20% fertilized their crops. The rest of pasture is practiced by only 14% and rotation by only 19% of family farms.

The use of adaptive strategies for droughts in the farm is analyzed by the existence of cisterns (*cistern*), wells (*well*), natural lake or weir (*weir*); and control of diseases or parasites in animals (*diseasec*). The construction of cisterns has been the main policy to fight droughts in the Brazilian semiarid region. A quarter of family farms in the region had cisterns in 2006. Weirs (or natural lakes) are also relatively frequent, 15%. And the control of diseases or parasites in animals is practiced by almost half of family farms.

Two variables defined by the FAO (Food and Agricultural Organization) and INCRA (National Institute of Colonization and Agrarian Reform) (Guanziroli 2001), helped to characterize the production system: the degree of specialization and the degree of market integration. The degree of specialization, which is measured by the ratio between the production value of the main product and the total production value, is analyzed by 3 categories: highly specialized (*specialized*1), with a degree of specialization equal to 1; specialized (*specialized*2), with a degree of specialization lower than 1 and greater than 0.65; diversified (*specialized*3), with a degree of specialization lower than 0.65. Almost half of farms did not have a specific specialization in agricultural production. In other words, the value of the main product of these family farms did not represent more than 65% of total production value.

In turn, the degree of market integration, which is measured by the ratio between the total revenue from agricultural activity and the total value of agricultural production was analyzed by the 3 categories: highly integrated (*integrated*1), with a degree of integration higher than 0.9; integrated (*integrated*2), with a degree of integration between 0.5 and 0.9; poorly integrated (*integrated*3), with a degree of integration between zero and 0.). More than half of the family farms were poorly integrated, i.e., their revenues from agricultural products represented less than 50% of total agricultural production, which reflects the prevalence of self-subsistence agriculture in the region.

Finally, the access to credit is analyzed by the binary variable *credit*, which identifies whether the family farm obtained funding from PRONAF (National Program to Strengthen Family Farming), which is the main public funding program for small family farms in Brazil. Although the percentage of farms receiving PRONAF in 2006 was substantially low (7%), it must be considered that this value refers only to loans contracted in 2006. Since the period of payment is up to 10 years, with up to 3-year grace period, the percentage of family farms assisted by PRONAF is probably much higher.

3.2. Statistical analyses

Climate clusters

In order to consider nonlinear patterns of relationship between climate and agricultural production, this study defined climatic clusters in the semiarid of Bahia. The variables used in these analyses are those presented in Table 1: average annual temperature (*avgtemp*), maximum temperature (*maxtemp*), minimum temperature (*mintemp*), relative humidity (*humidity*), annual precipitation (*precip*), total number of days in the year with preciption lower than 1 mm (*norain*). Each climatic cluster corresponds to a set of MCAs with relatively homogeneous values for the selected variables. The groups consider climate for the MCAs in each year of analysis (1974-2013). This means that there were 206 (MCAs) observations for each year of analysis, making 6,592 observations in 32 years with valid observations in the period. Thus, a MCA may belong to a specific cluster in one year and to another cluster in other year.

The classification of municipal observations in cluster was defined by the technique of Cluster Analysis (CA). The CA defines hierarchical groups of observations within a data set. There are several methods that can be employed in this process, but all are based on the same principle of hierarchical clustering. Initially, each observation is a cluster. The two closest clusters are joined to form a new cluster, and so on, until the method forms a maximum number of clusters that is predetermined according to the analytical convenience. The difference between the methods is basically the way the distance (or dissimilarity) between the clusters is calculated. The clustering method used in this study is the Ward method, an aggregation strategy based on the analysis of variance within and between the groups formed.

The aim of this method is to create hierarchical groups in such a way that the variance within the groups is minimal and the variances between the groups is maximal (Crivisqui 1999). The aggregation criterion consists of finding the next group which minimizes the variability within the newly-formed group. To facilitate the understanding of the variability within the groups, they are usually divided by the total variance to represent a ratio of the maximum achieved variability (R^2 semipartial).

Panel data analysis of the municipal production

The relationship between the dynamics of climate clusters and the agricultural production of MCAs was analyzed using panel data models. The analysis of panel data allows us to evaluate more accurately the cause and effect relations between the dependent (Y) and independent (X) variables, since it allow us to control unobserved factors associated with MCAs (c_i) which are considered constant in time. The dependent variable of each model is represented by the natural logarithm of the types of agricultural production. The logarithmic transformation aims to approximate to linearity the relationship between the dependent variable and covariates X. It also allows us to analyze the relative variation (%) in the type of production due to marginal variations in X. The relationship is given by:

$$\ln Y_{it} = \alpha + \sum_{j=1}^{k} \beta_j X_{j_{it}} + \delta t + c_i + \varepsilon_{it} \tag{1}$$

Where $\ln Y_{ij}$ is the natural logarithm of the dependent variable (*pmilk*, *cattle*, *goat*, *sheep* and *corn*) and X_j is the *j*-th regressor of interest. Covariates were represented by the rural population in the MCA (*prural*) and binary variables discriminating the climate clusters obtained in the previous analysis. The coefficient α is the intercept and β_j is net impact of X_j on $\ln Y$. The coefficient δ refers to the time trend of the dependent variable and represents for example, factors associated with technological advances and other unobserved factors that are constant between the MCAs in time. The factor c_i refers to unobserved factors that are associated with MCAs (human and social capital, or soil quality, for example). The variable ε is the idiosyncratic error, uncontrolled factors that are not associated with municipalities and/or time.

Although the factor c_i is not be observed, it can be controlled by the fixed effects approach (Wooldridge 2002). The fixed effects approach considers that the c_i factor represents a population parameter, which can be controlled through binary variables (binary variables estimator) or through algebraic transformations (*within* estimators). In this work, we adopted the *within* transformation, which, through algebraic transformations, excludes the factor c_i from the original specification (equation 1), preserving the relationship established for the other parameters of interest (α, β_j and δ). Estimators were obtained using the *xtreg* command from Stata software.

Cross section analysis of the small farm production

The potential impacts of the characteristics of farms and adaptive strategies on the production of family farming in the semiarid region of Bahia is based on models with cross-sectional data of the Agricultural Census 2006, sponsored by IBGE. The relationship between the variables is given by:

$$\ln Y_i = \alpha + \sum_{j=1}^{k} \beta_j X_{j_i} + \varepsilon_i \tag{2}$$

Where $\ln Y_i$ is the natural logarithm of the production of family farming. The subscript *i* refers to the *i*-th family farm. The set of dependent and independent variables (X_j) is presented in Table 2 and Table 3. Coefficients were estimated by the method of Ordinary Least Squares (OLS) using PROC REG procedure of SAS software. Standard error estimators are robust to heteroscedasticity and were obtained using ACOV option of PROC REG.

A model was adjusted for each type of production, whose dependent variables are very similar to those used in previous analyses of panel data models: (i) total liters of milk (variable *milk*); (ii) head of cattle (*cattle*); (iii) head of sheep (*sheep*); (iv) head of goat (*goat*); and (v) tons of corn per year (*corn*). The main difference in relation to the previous analysis refers to the dependent variable associated with milk production, which now refers to the total production in liters rather than the yield per cow. This modification is due to the fact that this model showed a greater explanatory power and has produced more consistent estimates for the coefficients. In any case, the analysis of production efficiency, measured by the milk yield (liters/cow) is not compromised because the number of cows (*cow*) is used as a control variable. In other words, the coefficients of this model indicate a greater or lesser production of milk holding constant the number of cows, thus giving a measure of production efficiency.

4. Results

4.1. Climate Clusters

Initially, CA was applied to identify groups of obsevations with relatively homogeneous values for the variables: average temperature (*avgtemp*), maximum temperature (*maxtemp*), minimum temperature (*mintemp*), relative humidity (*humidity*), annual precipitation (*precip*) days in the year with the precipitation lower than 1 mm (*norain*). Each observation represents a MCA in a specific year. Six clusters were initially selected, and the differences between the mean values of these clusters accounted for 91% of the total variability (R^2 semipartial) observed between the annual values of MCAs. Since one of the clusters represented a rare climatic condition, observed for a low number of observations (462), it was incorporated into the cluster with closer characteristics to permit a more significant analysis. Thus, analyses were based on 5 climatic clusters, with average characteristics presented in Table 4.

Table 4 – Average values of climate variables by climate groups, Semiarid of Bahia

Climate Variable	Climate Cluster				
	1	2	3	4	5
Observations	849	1,340	1,382	1,657	1,332
maxtemp	30.2	30.2	29.6	29.3	28.7
avgtemp	24.1	24.1	23.7	23.5	23.1
mintemp	19.1	19.3	19.1	18.9	18.9
humidity	65.7	68.2	70.1	71.3	75.1
precip	406	603	743	882	1,141
norain	284	279	268	257	237

Source: Elaborated using data from INMET

From the 1st to the 5th cluster, the climate conditions tend to be better, with lower average temperatures, and greater rainfall and humidity. Clusters 1 and 2 have the higher temperatures, lower relative humidity and precipitation and larger numbers of days with a precipitation lower than 1 mm. Cluster 1 presents more extreme conditions compared to cluster 2 with respect to precipitation, humidity and days without rain. Clusters 3 and 4 represent intermediate climate conditions in the region and cluster 5 presents the best climate indicators. For example, the average temperature in cluster 5 is 1.5 °C lower than in cluster 1 and the annual precipitation is almost 3 times higher.

4.2.The impacts on agricultural production

The analysis of the relationship between the dynamics of climate clusters and the agricultural production in the MCAs is based on the estimates of model for unbalanced panel data (Equation 1), containing information for the 206 MCAs in the semiarid of Bahia between 1974 and 2013. The aim of this analysis is to understand how the climate clusters positively or negatively affect each type of agricultural production in the MCAs. Five models were adjusted, one for each type of agricultural production (i) liters of milk per cow (*pmilk*); (ii) head of cattle (*cattle*); (iii) head of goats (*goat*); (iv) head of sheep (*sheep*); (iv) tons of corn (*corn*).

Among the independent variables X_j of the multiple regression model (equation 1), four binary variables were used to assess the impacts of climate clusters on agricultural production. For example, the binary variable *cluster*1 assumes 1 when the MCA i belongs to the climate cluster 1 in year t. The same is true for binary *cluster*2, *cluster*3 and *cluster*4. Cluster 5, which represents the best climate condition in the region, is used as reference of analysis. Thus, the coefficient β_j indicates the average difference between the climate cluster j and the Cluster 5 (reference). The expression $e^{\beta_j} - 1$ obtains the average relative difference (percentage) between the clusters (Halvorsen and Palmquist 1980).

Two other binary variables, *cluster*1_2 and *cluster*2_2, were also considered among the independent variables in order to evaluate the impacts of the recurrence of extreme climate events. These binary assume the value 1 if the climate groups with the most extreme conditions, clusters 1 and 2, occur repeatedly in two consecutive years. For example, if the MCA is classified in the climate cluster 1 for two consecutive years (t and $t-1$), the variable *cluster*1_1 assumes 1 in the year t. Thus, suppose that β_1 is the coefficient associated with the binary *cluster*1 and β_{1_2} the coefficient associated with the binary *cluster*1_2. The mean difference of Y between clusters 1 and 5 will be equal to $\beta_1 + \beta_{1\_2}$ when the MCA is classified in the cluster 1 for two consecutive years. That is, the relative difference between the mean values of the Y between clusters 1 and 5 will be given by $e^{\beta_1 + \beta_{1\_2}} - 1$. Similar analysis can be derived using the binary variable *cluster*2_2, which takes 1 when the MCA is classified in cluster 2 for two consecutive years.

The recurrence of clusters 1 and 2 for more than two consecutive years was tested, but ignored because results were insignificant. Similarly, the recurrence of other climate groups (3 and 4) was also tested, but their effects were largely insignificant, and the variables were dropped to facilitate analysis. It should be noted that the inclusion of lagged values of covariates (X_{t-1}) tends to generate multicollinearity, increasing the standard errors of the estimators.

The logarithm of the rural population was included among the independent variable as a proxy for labor supply in agriculture. A time trend was also incorporated in the model, which was controlled by the variable t with values ranging between 0 (for 1974) and 39 (for the year 2013). This variable identifies a common linear trend in the local production, which would be associated, for example, with technological or socio-economic development in the region.

Table 5 exhibits the fixed effects estimates for the coefficients of equation (1). Each column refers to one of the dependent variables. Estimates appear in the first line of each regressor. The p values consider standard errors robust to the presence of heteroscedasticity and autocorrelation. Table 5 also contains in its final lines statistics of goodness of fit. The total number of observations used in each estimation (n) differs between the models, since there is a distinct availability of data for each type of production. The statistics R^2 indicate that adjustments have explanatory powers ranging between 3% and 12%. These coefficients refer exclusively to variability within the MCAs, i.e., they do not account the variability between MCAs. All models showed significant statistics F, i.e., the models add significant contributions to explain each type of agricultural production. Although the values of R^2 are relatively low, the relatively low number of covariates used to explain a long history of extremely heterogeneous variations of municipal agricultural production must be highlighted. Several factors that affect production are not considered, such as access to infrastructure, credit, human and social capital, since these variables are not

available for the whole period of analysis. These variables are controlled by the fixed effects representing the municipal heterogeneities and the trend variable representing the temporal heterogeneity.

Table 5 – Fixed effect estimates for the agricultural production in the MCA, Semiarid of Bahia, 1974-2013

Regressors	Dependent Variable				
	ln(*pmilk*)	ln(*cattle*)	ln(*goat*)	ln(*sheep*)	ln(*corn*)
Intercept	-0.995	7.231 ***	8.213 ***	8.548 ***	9.186
ln(*prural*)	0.002	0.283 ***	-0.082	-0.039	-0.165
*cluster*1	-0.084 ***	0.000	-0.010	0.018	-1.298 ***
*cluster*1_2	0.001	-0.108 +	-0.073	0.086	-0.722
*cluster*2	-0.031 *	0.013	0.007	0.015	-0.627 ***
*cluster*2_2	-0.038 +	-0.029	-0.088 +	-0.097 **	0.057
*cluster*3	-0.031 +	0.033 *	0.061 +	0.039	-0.243 *
*cluster*4	0.000	0.046 ***	0.095 **	0.083 **	0.052
t	0.004 ***	0.002	0.024 ***	0.010 ***	-0.050 ***
n	5937	5732	5680	5565	2098
F	5.117 ***	5.217 ***	9.544 ***	6.947 ***	29.717 ***
R^2	0.026	0.022	0.147	0.062	0.114

Source: Elaborated using data from SIDRA (IBGE)
*** Significant at 0.1%; ** Significant at 1%; * Significant at 5%; + Significant at 10%.

The estimates for the coefficients associated with the rural population highlights that cattle raising is the most sensitive to the population size. The expected number of head of cattle increases by 0.28% for each 1% increase in the rural population. The other productions showed no significant relationship with the rural population, suggesting that cattle farming is the most labor intensive production in the semiarid of Bahia, albeit with a low elasticity.

The coefficients associated with each climate cluster indicate the relative differences between the mean production during the years in which the MCA is classified in a respective climate cluster and the years in which the same MCA is classified in the reference group (cluster 5). For example, the estimate for the coefficient associated with the cluster 1 (variable *cluster*1) for the milk yield suggests that holding constant other factors, the milk yield in the years in which the MCA is classified in the cluster 1 is on average 8.1% lower ($e^{-0,084} - 1$) than that observed in the years in which the MCA is classified in cluster 5. The occurrence of climate conditions similar to that of clusters 2 and 3 also negatively impacts the milk yield in MCA, when compared to the yield in the climate cluster 5. The mean yield in cluster 2 is 3.1% lower ($e^{-0,031} - 1$) than in cluster 5 and it is 3.0% lower ($e^{-0,031} - 1$) in cluster 3.

Although the impact of the second most extreme climate event (cluster 2) is lower than that of the most extreme event (cluster 1), the effects of cluster 2 are boosted when the MCA is classified for two consecutive years in this category. In these years (MCA classified in cluster 2 for two consecutive years), the mean milk yield is 6.7% lower ($e^{-0,031-0,038} - 1$) that that in the years in which the MCA is classified in cluster 5. Thus, while the main impact of more extreme climate event (cluster 1) in milk yield is of short-term, the impact of cluster 2 is of medium-term, i.e., with the recurrence of the climate phenomenon for two consecutive years in the same locality.

The most significant impact of climate change on the number of head of cattle occurs with the recurrence of extreme events, particularly the classification of the MCA in the climate cluster 1 for two consecutive

years. In such years, the number of head of cattle is on average 10.2% lower ($e^{0,000-0,108} - 1$) than in cluster 5. The recurrence of extreme weather events also tends to cause significant impacts on the head of sheep and goats. When the MCA is classified in cluster 2 for two consecutive years, the number of head of goats is on average 7.7% lower ($e^{0,007-0,088} - 1$) than that of the years in which this same locality is classified in the climate cluster 5. The value is 7.9% lower ($e^{0,015-0,097} - 1$) for the number of head of sheep.

Among the types of agricultural production analyzed, the corn production is undoubtedly the most affected by climate change in the semiarid of Bahia. In years when the MCA is classified in the three hottest and driest climatic clusters (clusters 1, 2 and 3), the average corn production is substantially lower than in the years when the same locality is classified in cluster 5. For example, compared to the years in which the MCA is classified in cluster 5, corn production is on average 72.7% lower ($e^{-1,298} - 1$) when the climate conditions in the MCA is equivalent to the cluster 1; 46.6% lower ($e^{-0,627} - 1$) when such conditions are equivalent to that of cluster 2; and 21.6% lower ($e^{-0,243} - 1$) when the MCA is classified in cluster 3. The impacts in corn production are of short- term, i.e., it occurs in the same year as the climate event, since the recurrence of the most extreme events (clusters 1 and 2) has shown an insignificant impact on corn production.

Finally, the coefficients associated with the variable t indicate trends for each type of production in time, assuming constant the climate conditions and the dynamics of the rural population (control variables). The trends for the milk yield and the cattle farming are not relevant. In turn, the trends for sheep and especially goats present the most substantial growth: 1.1% per year ($e^{0,010} - 1$) for sheep and 2.4% per year ($e^{0,024} - 1$) for goats. In turn, corn production fell in the period, with a negative trend of 4.9% per year ($e^{-0,050} - 1$).

4.3. Adaptative strategies for small farms production

The potential impacts of the farms' characteristics on the production of family farming in the semiarid of Bahia are estimated by multiple linear regression models fitted to the 2006 Agricultural Census data (Equation 2). A model for each production type was adjusted, with some adaptations in the dependent variable compared to the previous analyses: (I) total liters of milk (variable *milk*); (ii) cattle herd (*cattle*); (iii) sheep herd (*sheep*); (iv) goats (*goat*); and (v) corn production (*corn*). The natural logarithm was also applied to all the dependent variables to obtain a linear relationship between the variables. The main difference from the previous analysis refers to the dependent variable associated with milk production, which now refers to the total milk production in liters (and not to the production per cow). The reason is that this model has shown a greater explanatory power of the dependent variable and presented more accurate estimates for the model coefficients, besides a greater explanatory power. In any case, the analysis of productive efficiency, measured by the milk productivity (liters / cow) is not compromised because the number of cows (*cows*) was used as a control variable. In other words, the coefficients of this model indicate a higher or lower impact on milk production while keeping constant the number of cows, thus giving a measure of production efficiency.

The set of independent variables used as determinant and control of production are presented in Table 6 (producers' and farms' characteristics) and Table 7 (production systems' characteristics). The climate conditions were controlled by four binary representing the MCAs classification in 2006, according to the methodology explained in Part 2: *cluster*1, *cluster*2, *cluster*3, *cluster*4. The climate cluster 5 is used as reference for the analysis. Unlike previous analyses with panel data (Equation 1), the analysis of the equation 2 does not necessarily establish a cause and effect relationship between the independent variables and the agricultural production. This is because climate clusters tend to be correlated with unobserved factors in the territory, which also determine the production, such as the adaptability of the producer to regional conditions. Nevertheless, the most important result of these cross-sectional models is

to allow the assessment of the conditional association between adaptation strategies and agricultural production. However, these analyses should also be performed with caution because a conditional association relationship does not necessarily mean a cause-effect relationship.

Table 6 – Ordinary least square estimates for the characteristics of the small fams and farmers with heteroscedasticity-consistent standard errors, Semiarid of Bahia, 2006

Regressors	Dependent Variable				
	ln(*milk*)	ln(*cattle*)	ln(*goat*)	ln(*sheep*)	ln(*corn*)
Intercept	0.419 *	0.906 **	0.272 **	0.249 **	5.314 **
cow	0.586 *	-	-	-	-
ln(*acorn*)	-	-	-	-	2.113 **
ln(*anatpast*)	0.012 **	0.080 ***	0.047 ***	0.047 ***	-
ln(*adegpast*)	0.027 **	0.112 **	-0.009 **	-0.004 **	-
ln(*andegpast*)	0.038 **	0.159 ***	-0.015 ***	0.005 ***	-
ln(*aforage*)	0.126 **	0.121 **	0.079 **	0.109 **	-
ln(*aforest*)	-0.003 **	0.056 ***	0.032 ***	0.010 ***	-
lf	0.014 **	0.016 ***	0.013 ***	0.017 ***	0.009 **
coop	-0.121 *	0.066 *	0.029 *	0.049 *	-0.020 *
assoc	0.086 **	-0.086 **	0.033 **	0.054 **	0.009 **
female	-0.115 **	-0.152 **	-0.027 **	-0.036 **	0.071 **
age30_39	0.025 **	0.047 **	-0.014 **	-0.011 **	-0.034 **
age40_49	0.0431 **	0.1004 **	-0.0241 **	-0.0148 **	-0.0761 **
age50_59	0.0680 *	0.1487 **	-0.0417 **	-0.0095 **	-0.0796 **
age60	0.0764 *	0.2391 **	-0.0519 **	-0.0236 **	-0.0789 **
school01	0.048 **	0.075 **	0.032 **	0.002 **	-0.039 **
school02	-0.023 *	0.146 **	0.038 **	0.038 **	-0.029 **
school10	0.008 **	0.099 **	-0.015 **	-0.037 **	-0.047 **
school11	-0.063 *	0.166 **	-0.025 **	-0.046 **	-0.084 **
school21	-0.185 *	0.177 **	-0.087 **	-0.103 **	-0.141 **
school31	-0.437 *	0.207 *	-0.083 *	-0.078 *	-0.222 *
N	509,775	505,136	505,136	505,136	505,136
F	14,656 ***	14,817 ***	4,120 ***	3,452 ***	112,700 ***
R^2	0.543	0.540	0.246	0.215	0.884

Source: Elaborated using microdata of the Demographic Census 2010.
*** Significant at 0.1%; ** Significant at 1%; * Significant at 5%; + Significant at 10%.

The estimates for each type of production are presented in Tables Table 6 (characteristics of the farms and of the farmers) and Table 7 (characteristics of the production system). All the adjustments were significant, that is, with at least one estimate statistically different from zero (*F* statistics). The coefficients of determination of the adjusted models (R^2) vary between 21% (sheep) and 88% (corn), highlighting reasonable goodness of fit measures.

As expected, the farm area, used as proxy of physical capital, tends to have significant and positive association with the production. The marginal effect tends to be larger to the area with forage cultivation. For example, for each 1% increase of the forage cultivation in the farm's total area, one expects an increase of 0.13% in the milk production, keeping constant the other variables. Cattle is particularly

influenced by the area with non-degraded grazing (elasticity of 0.16%), while goats and sheeps are less influenced by the grazing areas, probably because of their ease in adapting to different environmental conditions. The livestock appear to depend mostly on forage areas. In turn, corn is extremely elastic to cultivated area: for each 1% variation in the area, a variation of 2.1% in the production is expected. This is an expected result, since corn production in these areas employs very low levels of technology and lis strongly correlated with the total cultivated area.

On the other hand, the total workers in the agricultural activity have little impact on production since other factors are controlled. For example, for each additional worker, a variation of only 1.6% in the cattle production is expected, keeping constant the other production factors. These results should be analyzed with caution, though they initially suggest that the production of family farming in the semi-arid of Bahia is inelastic to the use of labor, since it would be associated with very small-scale production.

The association of cooperativism with livestock production is positive and significant, but insignificant with the cultivation of corn and negative with milk production. The average production of the cooperative farms is 6.9% higher ($e^{0.066}-1$) than that of non-cooperative farms for cattle production, 5.1% ($e^{0.049}-1$) for the sheep production and 3.0% superior ($e^{0.029}-1$) for the goat production, *ceteris paribus*. The negative association of cooperativism with the milk production would probably relate to the lower scale of the family agricultural production associated to the local cooperatives. The most productive milk producers tend to be those associated with the agriculture association membership: production is on average 8.9% higher ($e^{0.086}-1$) than those of non-associated. Similarly, sheep and goat production also tends to be higher for producers associated with the agriculture association membership: 3.3% ($e^{0.033}-1$) and 5.5% ($e^{0.054}-1$), respectively.

Farms run by women predictably present a lower livestock production than men's due to the need for heavy manual work. Such a lower average production value may be also associated, for example, with the absence of a partner to share the livestock activities, which usually demand intense physical effort. The production is 14,1% lower ($e^{-0.152}-1$) for the cattle. In the corn production, farms managed by women tend to present a bigger production (7,4% higher on average), which probably would be associated with a greater allocation to agricultural practice.

The milk and cattle production tend to be greater for those farms managed by older people. For example, the number of cattle on the farms managed by over 60-year olds are on average 27% higher ($e^{0,2391}-1$) than that of those farms managed by people up to 29 years old. The acquisition of cattle, particularly of selected species, requires capital accumulation that may be not be easily accessible to younger farmers. Farms run by younger people tend to be associated with the production of goat, sheep and especially corn, which require lower initial capital.

Education is another important factor in explaining all types of production. The higher the educational level, the greater will be the production of cattle and lower the production of other agricultural activities (milk, goats, sheep and corn). Farmers that can only read and write (variable *escola*01) present, for example, a production of cattle that is 7.8% ($e^{0,075}-1$) higher than that of farmers with no education. Production grows more intensively if the farmer has fundamental education or more (variables *escola*11, *escola*21 and *escola*31). For example, production is on average 23% higher ($e^{0,207}-1$) if the farmer has finished university education (compared to the production of those with no education). In turn, the strongest negative association was observed for the production of milk, suggesting a strong specialization of production among those more educated (cattle) and less educated (milk).

The use of animal traction is positively associated with milk and cattle production, while the use of mechanical traction is positively associated with milk and corn production. The mean production of milk, for example, is 21.8% ($e^{0,197}-1$) higher on farms with mechanical traction, holding constant other factors. In turn, the number of head of sheep and goats is negatively associated with the use of animal and mechanical traction, suggesting that these types of production prevail in fams employing lower levels of technology.

Table 7 – Ordinary least square estimates for the characteristics of the systems of production and adaptive strategies with heteroscedasticity-consistent standard errors, Semiarid of Bahia, 2006

Regressors	ln(milk)		ln(cattle)		ln(goat)		ln(sheep)		ln(corn)	
atraction	0.197	**	0.0513	**	-0.004	**	-0.025	**	-0.025	**
mtraction	0.077	**	-0.022	**	-0.117	**	-0.022	**	0.085	**
guidance	-0.024	*	-0.042	**	0.220	**	0.225	**	-0.048	**
soilcor	-0.107	*	-0.140	**	-0.196	**	-0.161	**	-0.135	**
fertilizep	0.239	*	0.011	*	0.240	*	0.232	*	-	
fertilizec	-		-		-		-		0.317	**
fallow	0.002	**	-0.050	**	-0.046	**	-0.033	**	0.042	**
rotation	0.556	*	0.482	**	-0.122	**	0.001	**	-	
well	0.080	*	0.112	**	0.044	**	-0.010	**	-0.043	**
weir	0.064	**	0.147	**	0.050	**	0.149	**	-0.021	**
cistern	0.106	**	-0.032	**	0.208	**	0.276	**	0.080	**
diseasec	0.842	**	0.909	**	0.211	**	0.316	**	-	***
*specialized*1	-0.142	**	0.053	**	-0.099	**	-0.199	**	-0.254	**
*specialized*2	0.249	**	0.142	**	-0.065	**	-0.099	**	-0.014	**
*integrated*1	-0.165	**	0.195	**	0.053	**	0.206	**	-0.137	**
*integrated*2	0.215	**	0.131	**	0.107	**	0.238	**	0.014	**
credit	0.150	*	0.074	**	-0.081	**	-0.060	**	-0.015	**
*cluster*1	-0.331	*	-0.366	**	1.641	*	1.201	*	-0.348	**
*cluster*2	-0.317	*	-0.101	**	0.508	**	0.469	**	-0.104	**
*cluster*3	-0.141	**	-0.072	**	0.090	**	0.286	**	-0.006	**
*cluster*4	-0.084	**	-0.015	**	-0.028	**	-0.026	**	-0.150	**

Source: Elaborated using microdata of the Demographic Census 2010.
*** Significant at 0.1%; ** Significant at 1%; * Significant at 5%; + Significant at 10%.

Family farms receiving technical guidance present a production of goats and sheep that is expressively higher than others: 24.6% for goats ($e^{0.220}-1$) and 19.7% for sheep ($e^{0.225}-1$). This result may reflect the efforts of local agencies of agricultural extension in disseminating the raising of goats and sheep in the region, species that would be more adapted to the climate conditions of the semiarid. For other activities, the differences are negligible.

The effect of fertilizer is positive and significant for most types of production, with the exception of cattle farming. For example, farmers that fertilize pastures present a mean milk production that is 27% ($e^{0.239}-1$) higher than others, irrespective of other control factors. Similar net effects are observed in the goat and sheep farming. The corn production is on average 37.2% higher ($e^{0.317}-1$) for producers using fertilization. In turn, the use of lime or other types of correction of soil pH is negatively associated with all types of agricultural production. These results indicate that the correction of soil pH would be more common in other agricultural activities in the state.

Pasture rotation is positively and significantly associated with milk production and cattle farming. Farmers who perform pasture rotation have a mean milk production 74.3% higher ($e^{0.556}-1$) than others, and a mean number of head of cattle 61.9% ($e^{0.482}-1$) higher. In turn, the fallow, resting or strategies to cultive crops for pasture recovery only has a positive association with the cultivation of corn, a crop that may be being used in crop-livestock integration. Nonetheless, this result reflects only the short-term

impacts on livestock. There is no information available to evaluate the impacts on the total value of production and or the sustainability of the system in the long term.

Among the production techniques under analysis, the control of diseases and pests in animals is the one with the largest partial effects on livestock farming. Farmers who perform this type of control have a mean number of head of cattle that is more than twice as high as others ($e^{0,842}-1 = 132.2\%$). The impact is lower in the case of goat farming ($e^{0,211}-1$), suggesting that this species is more resistant to diseases and parasites that occur in the region.

Common adaptive strategies in the region, such as the use of wells, tanks and cisterns, have different effects on agricultural production. The partial effect of wells is higher in the cattle farming: production 11.9% higher ($e^{0,112}-1$) for those with wells. The use of lakes and weirs is also positively associated with cattle farming - production that is 15.9% higher ($e^{0,147}-1$) - sheep farming - production 16,0% higher ($e^{0,149}-1$). In turn, the use of cisterns is more associated with goat and sheep farming: the production of goats is on average 23.2% higher ($e^{0,208}-1$) in farms with weirs and the sheep production is on average 31.8% higher ($e^{0,276}-1$).

Specializing in few agricultural products does not have a unidirectional effect on all types of activities. The high specialization has a positive effect only on cattle farming. Even so, the partial effect is not very substantial. Highly specialized farms, that is, where the value of the agricultural production comes almost exclusively from the cattle farming, present a production that is on average 5.5% ($e^{0,053}-1$) higher than diversified farmers, irrespective of other characteristics. In turn, specialization in the production of milk, with some diversification into other agricultural activities, shows relevant positive results: the production is on average 28.3% higher ($e^{0,249}-1$) than diversified farmers. Moreover, the results of specialization, especially high specialization, is significantly negative for the production of goats, sheep and corn. For example, the average production of goats from highly specialized farmers is 9.5% lower ($e^{-0,099}-1$) than that of diversified farmers. These results may suggest that the integration of an agricultural crop with sheep and goat farming would have a positive impact on these activities.

In turn, the degree of integration with the market, i.e., the share of the total agricultural production that is commercialized in the market, has a positive and significant impact on most types of production. The impacts of the high integration, in which virtually all agricultural production is sold in the market, is positive and significant, especially in the case of cattle and sheep farming. Highly integrated farms have a cattle production that is on average 21.5% higher ($e^{0,195}-1$) than poorly integrated farms, and a sheep production that is on average 22.9% higher ($e^{0,206}-1$). The effects are more relevant when there is more interaction between the production for sale and the production for self-consumption or animal feed. In integrated farms, where the ratio between the agricultural production and the revenue from agricultural production is between 0.5 and 0.9, the milk production, for example, is 24% higher ($e^{0,215}-1$) that that of highly integrated farms.

The access to agricultural credit (PRONAF) is positively related to milk production and cattle farming. For example, farmers who received PRONAF in 2006 showed an average milk production 16.2% higher ($e^{0,150}-1$) than those who did not. In turn, the access to PRONAF is negatively associated with the production of goats, sheep and corn, once other factors are controlled. These results would reflect the greater allocation of public credit resources to the livestock industry in the region.

Finally, climate variables identify associations between the climate conditions that farmers are submitted to and their agricultural production. The most relevant trends indicate a positive association between the production of sheep and goats to the most extreme climate groups (clusters 1, 2 and 3), as well as a negative association between cattle farming and milk production with the hottest and driest groups. That is, farms would naturally shift from cattle farming to raising goats and sheep since the climate conditions of the territory are getting worse.

5. Concluding remarks and policy implications

The climate changes observed in the semiarid of Bahia in the last 40 years are relevant. The average temperature has grown at a rate of 0.27^oC per decade, and the maximum temperature shifted from an average of 28.7^oC in the 1970s to 30.2^oC in the 2010s. At the same time, the number of days without rain over the year has increased (from an average of 251 in the 1970s to 275 in the 2010s), and total precipitation has reduced (from 923 mm to 667 mm). Short cycles of more extreme conditions were also witnessed in the second half of the 1980s and the first half of the 1990s, as well as a longer cycle in the 2000s.

In parallel with these climate changes, there is an accelerated abandonment of the rural areas and major structural breaks in the agricultural production. Recent climate changes in the semiarid of Bahia, such as the growth of average temperature and reduction of rainfall, are likely to cause significant adverse impacts on all types of production (milk, cattle, sheep, goats and corn). The impacts are more significant in the production of corn and these impacts are in short-term. The losses in milk production are also significant, and tend to worsen with the recurrence of extreme events. In livestock farming, the impacts are greater with the recurrence of extreme events, after which most of the producers tend to sell their livestock.

It must be highlighted that these results are based on the estimates of average impacts of different climatic groups on the municipal farming production over the period of analysis. The climate groups used in this study to estimate these impacts only summarize the main climate patterns, and are not able to represent the complexity of climatic phenomena that occur in the region. Periods of exceptionally atypical conditions can cause even more substantial losses in production, as observed in 1995 and 1996. Moreover, extreme situations that are recurrent tend undoubtedly to aggravate the scenario of production losses. Although the impacts of two consecutive years of extreme events have been tested, it must be considered that the statistical analysis with many lagged values of climate variables tends to present insignificant estimates due to the strong relationship among the independent variables (multicollinearity).

Another limitation of this analysis is that it only considers the impact of climate change on the whole agricultural production of a spatial locality. Unfortunately, there is no historical information disaggregated for the different types of farmers. In other words, these estimates are probably conservative, which means they underestimate the real impact on family farming production. The impactc would probably be greater among smallholder farmers, since they are usually subjected to the most vulnerable socioeconomic and productive conditions. Unfortunatelly, this factor could not be taken into consideration due to the unavailability of data.

This scenario of production losses is extremely troublesome in places which already face extremely vulnerable productive and socioeconomic conditions. Besides the climate conditions, the characteristics of farms, farmers and their production systems reinforce the low agricultural productivity in the semiarid of Bahia. Family farmers are largely unable to read or write, are of an advanced age, do not participate in cooperatives and employ few technological resources. Governmental policies to promote agricultural activity had a very limited range in 2006, since the percentage of producers receiving technical guidance for the production or even credit-oriented to family farming was very low.

The production of milk and cattle requires high initial investment and tends to be larger on farms run by older people. There is also a strong specialization of production in cattle among those with higher education, and of production of milk among those with less education. The association with cooperatives tends to generate more positive effects on livestock production (cattle, goats and sheep), while the association with farming associations tend to be more positive for the milk production.

Agricultural production also depends substantially on the characteristics of the production system, such as mechanization, technical guidance, soil treatment, access to credit and integration with the consumer market. Animal traction is associated with higher milk and beef production, while mechanical traction is associated with the highest production of milk and corn. Family farmers who receive technical guidance

have a production of goats and sheep markedly superior to the others, which is probably associated with the efforts of local agencies of agricultural extension in disseminating these activities in the region. Fertilization tends to generate positive and significant results in virtually all types of activity, while the pasture rotation generates positive and substantial effects on milk production and cattle farming.

The control of diseases and parasites in animals also appears to be a key strategy for increasing livestock production. Rural credit in the region is strongly directed to the production of cattle and milk. Among the most widespread strategies of adaptation to drought in the region, cisterns can bring positive results to the sheep and goat farming, while the use of lakes and weirs would be more positive for cattle and sheep farming.

The positive impacts of some characteristics on agricultural production provide important elements to address adaptive measures to the negative impacts of climate changes. Albeit still limited in the region, institutional policies aimed to promote access to education, credit and technical guidance showed significantly positive impacts on different types of production and should be prioritized, as well measures to increase the technification of the production system or even the integration of family farmers in supply chains in the region.

In this sense, local, state and federal government institutions need to introduce new resilience measures that are economically efficient. Among the main strengthening links in climate resilience, the following are suggested: (i) a productive climate resilience reference system; (ii) credit oriented to finance this system; (iii) technical assistance for its implementation; (iv) strengthening of cooperative institutions; (v) agro-industrialization of products to add value, and (vi) improving access to markets.

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