Resilience Strategies to Agricultural Shocks and their Effects on Family Farms in Rural Areas in Senegal

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ABSTRACT

Family farming is an important source of income for rural populations in Senegal. But, because of the effects of agricultural shocks coupled with the vagaries of climate change, farmers are often unable to increase their production, let alone their income. Faced with these shocks and hazards, farmers feel compelled to adopt adaptation, resistance and prevention strategies for potential future shocks. The objective of this research is to analyze the resilience strategies of family farms in rural Senegal in response to agricultural shocks, and to assess the effect of these resilience strategies on the productivity of farms and the income of farmers. To do this, we focus on three specific objectives. First, we identify common resilience strategies to agricultural shocks among family farms in rural Senegal based on a descriptive analysis of the 2018/2019 Senegal Annual Agricultural Survey. Then, we identify the main factors that limit or promote the adoption of resilience strategies by farms using a multinomial Probit model. Finally, we assess the impact of resilience strategies on the productivity of family farms and on the income of rural farmers using endogenous switching regression. The value of this research is to provide decision makers with a solid basis for formulating policies aimed at redesigning agricultural programs and investment decisions.

Keywords: Agricultural shocks, Farms, Rural areas, Agricultural production, Farmers' income, Resilience strategies, Senegal.

JEL: Q15, Q18, O13, O18

I. INTRODUCTION

The health crisis caused by the Covid-19 pandemic came on top of a number of preexisting agricultural shocks (rising prices of inputs, crop pests, crop diseases, etc.) and climatic hazards (flooding, extended seasons, etc.) that threaten rural farm households. Agriculture contributes between 30-40% of gross domestic product (GDP) in African countries, and small-scale farm households are the fundamental basis for food security and prosperity of rural communities (Asfaw et al., 2018; Call et al., 2019; Makate et al., 2019). As a consequence, agricultural shocks and extreme weather conditions that negatively influence farmers' welfare and farm productivity also threaten rural economies overall (IPCC 2021). In response to perceived vulnerability, farms may adopt resilience strategies (also known as adaptation, resistance, and prevention strategies) to mitigate future shocks (Fatemi et al., 2017; Aryal et al., 2016). Such resilience strategies might include adjustment of agronomic practices (changes in the agricultural calendar, soil conservation, irrigation), changes in agricultural processes (crop diversification), and capital investments (income diversification), among others (Devkota et al., 2017; Niles et al., 2016; Zhang et al., 2015).

Due to agricultural shocks and extreme climatic conditions, alongside growth in other non-farm sectors of the economy, agricultural Gross Domestic Product (GDP) in Senegal fell from 30% in the 1960s to 20% at the end of the 1970s to around 10% today (World Bank, 2021). Senegalese agricultural production systems remain overwhelmingly small-scale and family-based, with 95% of producers having less than two hectares of land; and yet the sector also constitutes the main source of income and employment for the rural population (World Bank, 2021). Despite the social and economic importance of the agricultural sector, agricultural productivity remains low with more than half of Senegalese farmers practicing subsistence agriculture, living below the poverty line and affected by food insecurity. Rural farm communities in Senegal are also exposed to a variety of agricultural and climatic shocks that prevent farmers from accumulating assets and human capital that could help reduce poverty (World Bank, 2006). This makes them more vulnerable to natural disasters, economic shocks (e.g., exchange rate variability, international price fluctuations), health crises such as the Covid-19 pandemic, and increasingly irregular rainfall and worsening crop pest and disease conditions associated with climate change. This vulnerability is likely to further increase with a rise in temperature of around 2 to 4 °C anticipated by 2100, alongside a drop of 5 to 10% in cloud cover, reductions in rainfall of 5 to 25%, increasing aridification of the northern part of Senegal, an upsurge in coastal erosion, and a rise in sea level of 1 m (Lacroix et al., 2021). These constraints are predicted to reduce annual cereal productivity in Senegal by as much as 50% (CIRAD, 2021), and to increase food insecurity by 17%, resulting in nearly 47% of the population living in poverty (FAO, 2017).

Faced with this situation, the Government of Senegal has adopted several means to stimulate rural farms' adaptation to climate change, including the creation of Polyvalent Rural Expansion Centers (CERP), Regional Development Assistance Centers (CRAD), the Agricultural Marketing Office (OCA) and the Senegalese Development Bank whose primary objective is to support rural farms, businesses and communities. Alongside these institutions, the Government has also allocated 4.3% of the national budget to the agricultural sector (CEA, 2017).[1] Despite this state investment, farmers face production constraints related to desertification (20% to 25% depending on the region), water limitations (14%), phytosanitary constraints (8%), steep slopes (11.2%), and water erosion and wind erosion (4%) (EAA, 2018). With this situation, resilience

[1] This amount is of course lower than the target of the Maputo Declaration of devoting 10% of the budget to agriculture (CEA, 2017)

strategies remain necessary to reduce the vulnerability of farms to agricultural and climatic shocks (Gregory et al., 2005).

Resilience is a complex phenomenon, comprising different strategies that can play important roles in improving the living conditions of farmers. Broadly defined, resilience is the adjustment of natural or human systems to respond to current or expected situations, to moderate or adapt to negative consequences and to take advantage of opportunities changing conditions may present (Di Falco et al., 2011; IPCC, 2001). Thus, the resilience of farms in Senegal consists of the adoption of different strategies depending on the perception of risks, local knowledge of adaptation strategies, and resources available to adapt. Senegalese farmers use a range of strategies including crop diversification (37.5%), use of traditional practices, knowledge and heritage (30%), use of seeds adapted to local conditions and stresses (22.9 %), sale of animals (27.6%), diversification of farm and household activities (27.5%), sale of crops (22.2%), irrigation (7.6%) and drawing on government support (20.8%) (EAA, 2021). This study asks: what are the impacts of resilience strategies seeking to mitigate agricultural shocks on family farms in rural Senegal? Specifically:

- What factors limit or promote adoption of resilience strategies among rural farm households facing agricultural shocks?
- What are the impacts of resilience strategies on the productivity of family farms, and the incomes of rural farm households?

This research provides multiple contributions to the literature on agricultural adaptations to economic and climate-related shocks. Although there is a significant literature on agricultural shocks and climate variability, past work is largely limited to examining relationships between climate change adaptation strategies and agricultural yields (Khanal et al., 2018a; Khanal et al., 2018; Quan et al., 2019). Studies in African countries are further limited to Ethiopia, Ghana, Nigeria and Mali (Diallo and Donkor, 2020; Onyeneke, 2020), with only rare and very recent studies in Senegal analyzing perceptions, impacts and adaptations to climate change (Cissé and Khalifa, 2022; Basse et al., 2022; Diallo et al., 2022). There thus remains a gap in the literature concerning the impact of resilience strategies seeking to mitigate agricultural shocks on farms in rural Senegal. This research aims to fill this gap by combining multivariate Probit regression models examining farmers' choice of adaptation strategies, with endogenous switching regression and propensity score matching approaches to consider the impacts of adaptation strategies on farm production and household incomes. This empirical approach makes it possible to compare observed outcomes across farmers who have adopted resilience strategies and very similar farm households who have not. This also makes it possible to evaluate the relative effectiveness of alternative resilience strategies for family farms in rural Senegal.

This work is organized as follows: Section II presents the literature review, and Section III summarizes the methodological approach. Section IV presents results and discussions, and Section V presents robustness tests. The final section concludes.

II. REVIEW OF LITERATURE

2.1 Agriculture in Senegal

Agriculture is a key driver of economic growth in Senegal. In 2021, the contribution of agriculture to GDP growth was estimated at 15.32%, with agriculture occupying 30% of total jobs (World Bank, 2023). In this context, agricultural development has been placed at the heart of Senegal's development policy, with an emphasis on the goal of ensuring a successful structural transformation of the economy. The implementation of the Emergent Senegal Plan (PSE) since 2014 has enabled Senegal to maintain economic growth of an average of 6.6% from 2014-2018, with projections suggesting a growth rate of around 10.2% from 2019-2023 despite the negative impacts of the Covid-19 crisis and the war in Ukraine (AfDB, 2023). This growth has been mainly driven by a combination of the tourism and agriculture sectors, but also by the export of oil and gas expected in 2023. Despite this economic growth, the poverty rate is estimated at 37.8% in 2018/2019, and is highest in rural areas (53.6% versus 19.8% in urban areas) (ANSD, EHCVM, 2018/2019).

Agriculture remains the main livelihood activity in rural communities in Senegal. Production is mainly rain-fed, with the primary growing season lasting a maximum of three months and varying somewhat across agroecological zones (the Groundnut Basin, the Casamance, the River Valley, the Niayes zone and the Silvopastoral zone). Comprised of overwhelmingly small-scale, low-input, climate-dependant production systems, Senegalese agriculture bears the full brunt of shocks linked to the degradation of productive natural resources including soil, water, and forests, as well as broad impacts from climate change (Cissé and Diop, 2022). These are manifested by irregularity of rains and a rise in temperatures, and have a considerable negative impact on agricultural productivity and household incomes. Increasingly frequent climate shocks thus undermine growth of the agricultural sector and further accentuate poverty.

To face these crucial challenges, the Government of Senegal is investing in agriculture through the Senegalese Agriculture Acceleration Program (PRACAS) which translates the State's overall economic development goals into medium- and long-term economic and social policy through the Emerging Senegal Plan (PSE). This program is structured around four axes, namely: (1) the promotion of family farming through intensification, expanded marketing and better quality management; (2) the emergence of agricultural and rural entrepreneurship in synergy with agribusiness yet respectful of the environment and supporting adaptation to climate change; (3) involvement of young people and women in the agricultural sector with the establishment of job-generating larger-scale farms and investments in technical knowledge and appropriate equipment; and (4) reinforcing the resilience of vulnerable populations via diversification of production and satisfaction of cereal needs at the national level (FAO, 2023).

Thus PRACAS, with the aim of improving resilience in agriculture, focuses on sustainable land management in order to reduce the process of land degradation and boost agricultural production across agro-ecological zones. For this purpose, a variety of techniques are implemented. These include assisted natural regeneration (RNA), erosion control, agroforestry techniques for restoring degraded land, organic and mineral amendments, and water saving through improved production practices.

2.2 Agricultural shocks and resilience

The existing literature considers two main sets of factors associated with the use of resilience strategies among rural farm households. On the one hand, numerous empirical studies have shown that farm characteristics such as farm size and other enabling factors influence management practices including use of adaptation and resilience strategies (Piya et al., 2013). Access to credit, extension services and climate information is also often associated with shifts from traditional coping strategies to adoption of modern resilience strategies in response to agricultural and climatic shocks (Bryan et al., 2009; Deressa et al, 2009). At the same time, other studies have identified farmers' perception of risks from shocks as key determinants of proactive adaptation decisions (Zheng et al., 2016), with ultimate changes in farm behavior a function of both risk perception and farmer capacity to invest in resilience.

Farmers have employed many resilience strategies in response to the impacts of agricultural and climatic shocks. Key farm-level adaptations identified in the literature include use of different crop varieties, investment in soil and water conservation, improved irrigation, diversification of income-generating activities, and accessing agricultural insurance (Biggs et al., 2013; Yila & Resurreccion, 2013). For example, in Mali, due to the shortening of the rainy season, many farmers have adopted shorter-cycle sorghum varieties (Lacy et al., 2006). And in the Ashanti region of Ghana, farmers have diversified crops and changed planting dates in response to lower rainfall and higher temperatures (Fosu-Mensah et al., 2012). Farmers across Africa (Wang et al., 2012) and Latin America (Seo & Mendelsohn, 2008) have made changes to crop portfolios and farm practices to adapt to various challenges, subject to the socio-economic, farm, institutional and agro-ecological constraints they face (Tarfa et al., 2019; Soglo & Novinde, 2019).

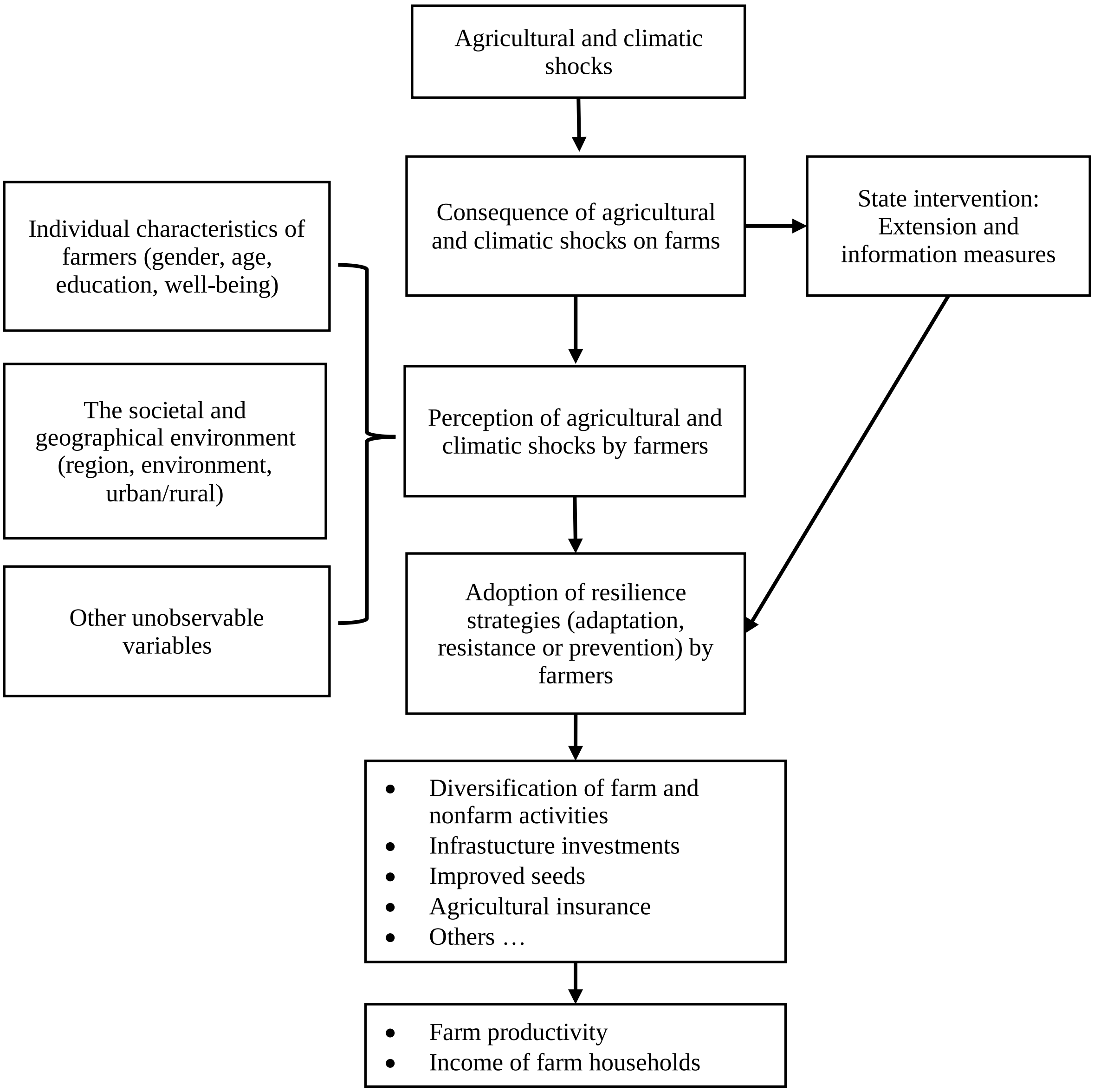
There is an abundant literature evaluating the impacts of resilience strategies on agricultural production. However, many of these studies consider only a few coping strategies in their analysis (Waha et al., 2013) or are focused at a macro level (Challinor et al., 2014). These studies provide important information on the design of adaptation strategies at the global, regional or national level, but for effective and robust adaptation planning at the local level, it is important to understand the impacts of specific adaptation practices at the farm and community level. In recent years, a few studies have examined the impact of coping strategies on agricultural productivity, taking into account the varied coping strategies employed by farmers (Di Falco et al., 2011; Huang et al., 2015). Onyeneke (2020) highlighted the productivity benefits of a range of adaptation strategies among rice producers in Nigeria including adoption of minimum tillage, improved soil management and drainage, fertilizers, crop diversification, livelihood diversification, improved seeds, pesticides, seedling nurseries and the adjustment of planting and harvest dates. And in one of the few previous empirical studies in Senegal, Bass et al. (2022) found that good agricultural practices were an effective tool to increase the productivity of Senegalese cashew producers.

Although there is a significant literature on the analysis of agricultural shocks and climate variability, it is largely limited to examining the relationship between climate change adaptation strategies and agricultural yields in at-risk areas (Khanal et al., 2018a; Khanal et al., 2018; Quan et al., 2019). Moreover the set of existing studies in African countries is limited to the cases of Ethiopia, Ghana, Nigeria and Mali (Diallo & Donkor, 2020; Onyeneke, 2020). There are few available previous studies analyzing perceptions, impacts and adaptations to climate change in Senegal (Cissé & Khalifa, 2022; Basse et al., 2022; Diallo et al., 2022).

2.3 Conceptual model

Building on the previous literature, in this paper we conceptualize the behavior of farms faced with the perceived risk of an agricultural and climatic shock as a function of the individual characteristics of farmers (sex, age, education, well-being), the characteristics of the farms (cultivated area, etc.), the societal and geographic environment (region, environment, urban/rural), the perceived risk of consequences (economic, security, environmental) of shocks, and finally state intervention (Figure 1). Although there are several resilience strategies possible, we focus on the adoption of preventive measures recommended by the WHO and emphasized in previous research including the diversification of on-farm and off-farm income-generating activities, infrastructure investments such as irrigation or erosion control measures, improved seeds, and others. In many cases, farms that adopt such resilience measures not only protect themselves against agricultural and climatic shocks, but also enhance resilience to economic and social stressors (as seen through the Covid-19 pandemic) that can undermine agricultural systems and also affect the production of farms and the profitability of farmers.

Figure 1: Hypothesized channels through which agricultural and climatic shocks affect farm productivity and farm household income.



Source: Authors

The impact of resilience strategies seeking to mitigate agricultural shocks on farms in sub-Saharan Africa is poorly documented; particularly in Senegal. This study aims to fill this gap through a combination of econometric approaches including multivariate Probit models and an endogenous switching regression to better understand the impacts of three types of resilience strategies: the construction of dikes, crop rotation, and use of certified seeds. This empirical approach makes it possible to have more robust results by comparing differences in outcomes realized between farmers who have adopted resilience strategies and those similar farmers who have not adopted them. We are thus able to test the effectiveness of resilience strategies to agricultural shocks for enhancing productivity and incomes for family farms in rural Senegal.

III. DATA AND METHODS

3.1 Data

This work draws on data from the 2018/2019 Senegal Annual Agricultural Survey (AAS). This survey collected information from 5,888 households, including 54,488 household members. The survey includes data on all surveyed households and all agricultural plots within these households, and is representative of the 45 departments of Senegal. Data are collected in two stages. The first stage collects information at the start of the cropping season (just after sowing) consisting of household characteristics and data on plots sown and the areas, types of crops, inputs and cultural practices of the agricultural season. This includes data on the physical characteristics of cultivated plots (geolocation, area) and major investments made in terms of agricultural inputs, cultivation operations, management, and soil restoration. The second stage collects post-harvest information on agricultural and plant production, as well as other agricultural activities (livestock, agroforestry), fishing and aquaculture.

In addition to drawing on survey responses including farmer self-reported exposure to climatic shocks, we also integrate climate data from meteorological stations in Senegal. These data include average monthly temperature and rainfall for the years 2017 and 2018 at all weather stations for the rainy and dry seasons across the agro-ecological zones in Senegal. The lack of sufficient spatial variation in key climate variables (temperature and precipitation) in cross-sectional data is a known problem for conducting micro-level research on climate change (Koudjom, 2022). This may be especially true in most developing countries where weather stations must cover a large geographic area. To address this problem, we used a spatial interpolation method (Wahba, 1990) to generate seasonally disaggregated average temperatures and precipitation (rainfall and dryness) for the different agro-ecological zones.

It should be noted that any spatial interpolation is subject to uncertainty associated with the choice of interpolation method, measurement errors, and variability in elevation, slope, and other spatial factors (Dandonougbo 2021). Given the limitations of the spatial interpolation of climate data, the recommended best practice to improve the quality of spatial estimations is to increase the density of the monitoring network and test the validity of the interpolation by carrying out a counter interpolation (Hutchinson 1998). We therefore used multiple alternative data points to interpolate the climate data, drawing on QGIS software to perform the interpolation. Similar procedures have been reported in previous literature (McKenney-Easterling et al., 2000; Di Falco et al. 2011).

3.2 Specification of the econometric model

First, we identify key resilience strategies of farms in the face of agricultural and climatic shocks. In the context of this research, resilience strategies are measures taken by farmers to adapt, resist or prevent future vulnerability to agricultural shocks (plant disease, variation in input prices, high rates of crop pests, fire, etc.) and climatic shocks (floods, drought, irregular rains, landslides, soil erosion, etc.). Farms in rural Senegal have adopted several strategies; we focus on three including the construction of dikes (C), crop rotation (R) and the use of certified seeds (S). Resilience being a capacity for anticipation, resistance and adaptation in order to maintain production in the face of a shock, farmers can draw on these measures to maintain activity by mitigating the shock, resisting or adapting after the shock.

After identifying key agricultural resilience strategies, we then examine factors that limit or promote adoption of these strategies using a multivariate Probit model. Faced with a shock, each farm may adopt nothing as a resilience strategy or adopt one or more strategies at a time. We know for each farm whether a strategy was used or not, but we do not know the intensity of its use. Let us consider C_i , R_i and S_i three indicator variables taking the value 1 if the farm has adopted a given resilience strategy and 0 otherwise. The values taken by these indicator variables are each determined by those of a latent variable, C_i^*, R_i^*, S_i^* which is unobserved, but which can be decomposed as the product of a vector of explanatory variables X and a vector of parameters $\beta_C, \beta_R, \beta_S$ and a stochastic portion represented by an error $\varepsilon_C, \varepsilon_R, \varepsilon_S$. These stochastic terms are assumed to be jointly distributed according to a normal distribution.

Formally, we obtain a system of three equations as follows:

$$\begin{cases} C_i = \begin{cases} 1 \; if \;\; C_i^* = X'_C \beta_C + \varepsilon_{Ci} \\ 0 \;\; if \;\; \text{not} \end{cases} & \text{(a)} \\ R_i = \begin{cases} 1 \; if \;\; R_i^* = X'_R \beta_R + \varepsilon_{Ri} \\ 0 \;\; if \;\; \text{not} \end{cases} & \text{(b)} \\ S_i = \begin{cases} 1 \; if \;\; S_i^* = X'_S \beta_S + \varepsilon_{Si} \\ 0 \;\; if \;\; \text{not} \end{cases} & \text{(c)} \end{cases} \quad (1)$$

Where

$$\begin{pmatrix} \varepsilon_{Ci} \\ \varepsilon_{Ri} \\ \varepsilon_{Si} \end{pmatrix} = MVN(0, \Sigma) \text{ with } \Sigma = \begin{pmatrix} 1 & \rho_{RC} & \rho_{SC} \\ \rho_{CR} & 1 & \rho_{SR} \\ \rho_{CS} & \rho_{RS} & 1 \end{pmatrix}$$

For identification purposes, we assume that $\text{var}(\varepsilon_{ij}) = 1 \; (j = C, R, S)$.

The equation defines a multivariate probit that predicts the probabilities of adopting the different agricultural resilience strategies. Equation 1 has a simultaneous structure that jointly determines the decision to adopt any resilience measures. This specification allows for the identification of correlations that may exist between the three latent variables that embody unobserved characteristics for farms. A univariate approach as shown by Griffith et al. (2006) would ignore potentially non-zero non-diagonal elements of the variance-covariance matrix. This would produce inconsistent estimates when there is a correlation between the error terms (Maddala, 1983). Under the block specification of equation 1, the probability of a family farm adopting one of the three resilience strategies is given by:

$$\{P(C = c, R = r, S = s) = \Phi_3\left[(2c-1)X'_C\beta_C, (2r-1)X'_R\beta_R, (2s-1)X'_S\beta_S; \tilde{\Sigma}\right] \quad (2)$$

With c, r, s = 0, 1

The parameters β and ρ_{ij} are estimated by maximum likelihood, with $\Phi_4(., \tilde{\Sigma})$ the Gaussian cumulative function of dimension 3 with $\tilde{\Sigma}$ the associated variance-covariance matrix. This model can be estimated consistently and efficiently by maximizing the log likelihood function:

$$LogL = \sum_{i=1}^{n} \log \Phi_3(X'_C\beta_C, X'_R\beta_R, X'_S\beta_S, | \rho_{CR}, \rho_{CS}, \rho_{RS}) \quad (3)$$

As shown by Cappellari and Jenkins (2003), the estimation of equation 3 is done by the maximum likelihood method simulated by the GHK (Geweke -Hajivassiliou-Keane) method. The GHK method exploits the fact that a multivariate normal distribution function can be expressed as a product of one-dimensional sequentially conditioned functions of the normal distribution, which can be easily and accurately estimated.

We next evaluate the impact of the adoption of the same three resilience strategies (construction of dikes (C), crop rotation (R) and the use of certified seeds (S)) on farm productivity and the income of rural farm households using endogenous switching regression, which takes into account observed and unobserved variables to correct for endogeneity and self-selection in the adoption of agricultural resilience strategies. Relying on the framework of random utility, we assume a farm chooses whether or not to adopt a resilience strategy depending on the characteristics of the farmers, the farm and the context. Adoption (A_i) is a visible manifestation of the unobservable latent variable (A_i^*) of the adoption decision.

$$A_i = \begin{cases} 1 \text{ if } A_i^* > 0 \\ 0 \text{ if not} \end{cases} \quad \text{with } A_i^* = Z_i\alpha + \varepsilon_i \tag{4}$$

Where $Z_i = (1, z_{i1}, z_{i2}, z_{i3}, ..., z_{ik})$ is a vector of explanatory variables, α a vector of parameters to be estimated, and ε_i is random error distributed according to a normal law. The adoption of a resilience strategy ($A_i = 1 \text{ or } A_i^* > 0$) can be influenced by current climatic factors, the perception of production shocks, access to financing, access to information on available agricultural innovations, access to agricultural extension, characteristics of the farmer and characteristics of the family farm.

To model the effect of the adoption of resilience strategies on the productivity of family farms, we explore several functional forms. The simplest approach to examining the impact of adopting resilience strategies would be to include in the farm productivity equation a dummy variable (A) equal to 1 if the farmer has adopted resilience measures in the face of agricultural shocks, then apply ordinary least squares (OLS) to predict productivity or income. However, this approach could yield biased estimates because it assumes that the adoption of an agricultural resilience strategy is exogenously determined when it is potentially endogenous. The decision to adopt an agricultural resilience strategy or not may be based on self-selection, i.e., farms that have adopted agricultural resilience strategies may have systematically different characteristics from those that have not.

In addition, farmers may have decided to adopt agricultural resilience strategies based on expected yields. Unobservable characteristics of farms and their operators can influence both the decision to adopt resilience strategies and agricultural performance; hence a risk of inconsistent estimates of the effect of adopting resilience strategies on agricultural productivity. Thus, taking into account the possible endogeneity of the decision to adopt resilience strategies, we estimate a model of simultaneous equations of adoption and agricultural yields with a full information maximum likelihood endogenous switching regression approach. Unlike studies that use the fitted values generated automatically by the non-linearity of the selection model to control for endogeneity (Fu et al, 2018; Aboal and Tasci, 2017), we use an exclusion restriction so that this model is identified (Abdulai and Huffman, 2014; Takam-Fongang et al., 2019). This restriction is necessary when there are some variables that directly affect the selection variable (adoption of resilience strategies), but not the outcome variable approximated by agricultural productivity (Coromaldi et al., 2015).

Thus, we use as selection instruments for the agricultural productivity function variables related to information on other agricultural shocks including the perception of sand / silting, and the use of seeds from personal reserves as well as seeds purchased on the local market. The admissibility of these instruments is effective after a sample homogeneity test and a tampering test (Di Falco et al., 2011). Therefore, if the selection instruments are valid, they will have an impact on the decision to adopt agricultural resilience strategies, but not on the productivity of farms that have not adopted them. To account for selection bias, we adopt an endogenous switching regression model of agricultural productivity in which farms face two regimes: adopting agricultural resilience strategies (regime 1) and not adopting them (regime 2). The regression model for yield is defined following that of Di Falco et al. (2011) and Abdulai and Huffman (2014):

$$\begin{cases}\text{Adoption of resilience strategies} & \text{(regime 1)}: \; Y_{1i} = X_{1i}\beta_1 + \mu_{1i} \;\text{ if } A_i = 1 \quad (a)\\ \text{No-Adoption of resilience strategies} & \text{(regime 2)}: \; Y_{2i} = X_{2i}\beta_2 + \mu_{2i} \;\text{ if } A_i = 0 \quad (b)\end{cases} \quad (5)$$

Where A is the probability of adoption of agricultural resilience strategies, Y_i represents the productivity within regimes 1 and 2, X_i represents the vector of the explanatory variables. β_1 and β_2 are the vectors of the parameters to be estimated, and the error terms ε_i, μ_{1i} *et* μ_{2i} in the selection equation (1) and yield (productivity) equation (3) are assumed to have a trivariate normal distribution with mean 0 and covariance matrix $\sum$ i.e., $(\varepsilon, \mu_1, \mu_2): \; N(0,\Sigma)$.

Where

$$\sum = \begin{pmatrix} \sigma^2_{\varepsilon} & \sigma_{\varepsilon\mu_1} & \sigma_{\varepsilon\mu_2} \\ \sigma_{\mu_1\varepsilon} & \sigma^2_{\mu_1} & . \\ \sigma_{\mu_2\varepsilon} & . & \sigma^2_{\mu_2} \end{pmatrix}$$

Where σ^2_{ε} is the variance of the error in the selection equation (4), which can be assumed equal to 1 since the coefficients can only be estimated up to a scale factor (Maddala, 1983), $\sigma_{\mu_1}{}^2, \sigma_{\mu_2}{}^2$ are the variances of the error terms in the yield functions (5a) and (5b), $\sigma_{\mu 1\varepsilon}$ and $\sigma_{\mu 2\varepsilon}$ represent the covariance of ε_i, μ_{1i} and μ_{2i}. As Y_{1i} and Y_{2i} are not observed simultaneously, the covariance between μ_{1i} and μ_{2i} is not defined. An important implication of the error structure is that, given the error term of the selection equation (6), ε_i is correlated with the error terms of the productivity functions (5a) and (5b). The expected values of μ_{1i} and μ_{2i} conditional on sample selection are zero:

$$\begin{cases} E\left[\mu_{1i} \middle| A_i = 1\right] = \sigma_{\mu_1\varepsilon}\dfrac{\phi(Z_i\alpha)}{\Phi(Z_i\alpha)} = \sigma_{\mu_1\varepsilon}\lambda_{1i} \\ \text{et} \\ E\left[\mu_{2i} \middle| A_i = 0\right] = \sigma_{\mu_2\varepsilon}\dfrac{\phi(Z_i\alpha)}{1-\Phi(Z_i\alpha)} = \sigma_{\mu_2\varepsilon}\lambda_{2i} \end{cases} \quad (6)$$

Where $\lambda_{1i} = \dfrac{\phi(Z_i\alpha)}{\Phi(Z_i\alpha)}$, $\lambda_{2i} = \dfrac{\phi(Z_i\alpha)}{1-\Phi(Z_i\alpha)}$, $\phi(.)$ is the standard normal probability density function and $\Phi(.)$ is the normal cumulative density function. Thus, we have:

$$\ln L_i = \sum_{i=1}^{N} A_i\left[\ln\Phi\left(\frac{\mu_{1i}}{\sigma_{\mu_1}}\right) - \ln\sigma_{\mu_1} + \ln\Phi(\theta_{1i})\right] + (1-A_i)\left[\ln\Phi\left(\frac{\mu_{2i}}{\sigma_{\mu_2}}\right) - \ln\sigma_{\mu_2} + \ln\left(1-\Phi(\theta_{2i})\right)\right] \quad (7)$$

Where, $\theta_{ji} = \dfrac{(Z_i\alpha + \rho_j\mu_{ji}/\sigma_j)}{\sqrt{1-\rho_j^2}}$, J= 1,2 with $\rho_1 = \dfrac{\sigma^2_{\mu_1\varepsilon}}{\sigma_{\mu_1}\sigma_{\varepsilon}}$ and $\rho_2 = \dfrac{\sigma^2_{\mu_2\varepsilon}}{\sigma_{\mu_2}\sigma_{\varepsilon}}$ meaning the correlation coefficient between the error term ε_i of selection equation (4) and the error terms μ_{ji} of equations (5a) and (5b) respectively. The importance of this regression model, as illustrated in equation 8, is that it allows, from post-estimate analyses, to compare the yield in terms of expected production of family farms that have adopted an agricultural resilience strategy (a) compared to farms that did not adopt them (b). In addition, one can evaluate the return in terms of expected production in the case of the hypothetical counterfactuals (c) for the farms which adopted the resilience strategies in case they had not adopted them, the same for the farms which did not adopt them. did not adopt these resilience strategies (d) in case they had adopted them. These conditional agricultural yield expectations in the four cases are defined as follows:

$$\begin{cases} E\left(Y_{1i} / A_i = 1\right) = X_{1i}\beta_1 + \sigma_{\mu_1\varepsilon}\lambda_{1i}, & \text{(a)} \\ E\left(Y_{2i} / A_i = 0\right) = X_{2i}\beta_2 + \sigma_{\mu_2\varepsilon}\lambda_{2i}, & \text{(b)} \\ E\left(Y_{2i} / A_i = 1\right) = X_{1i}\beta_2 + \sigma_{\mu_2\varepsilon}\lambda_{1i}, & \text{(c)} \\ E\left(Y_{1i} / A_i = 0\right) = X_{2i}\beta_1 + \sigma_{\mu_1\varepsilon}\lambda_{2i}, & \text{(d)} \end{cases} \qquad (8)$$

Cases (a) and (b) represent the actual expectations observed in the sample. Cases (c) and (d) represent the expected outcomes of the counterfactuals. In addition, following Heckman et al. (2001), we calculate the treatment effect of adopting an agricultural resilience strategy on the treated (ATT) as the difference between (a) and (c), which represents the effect of adopting agricultural innovations on the agricultural productivity of farmers who actually adopted a resilience strategy for their family farm.

$$ATT = E\left(Y_{1i} \middle| A_i = 1\right) - E\left(Y_{2i} \middle| A_i = 1\right) = X_{1i}\left(\beta_1 - \beta_2\right) + \left(\sigma_{\mu_1\varepsilon} - \sigma_{\mu_2\varepsilon}\right)\lambda_{2i} \qquad (9)$$

Similarly, it is possible to calculate the effect of the treatment on the untreated farmers (ATU) who did not adopt resilience strategies for their farms as the difference between (d) and (b).

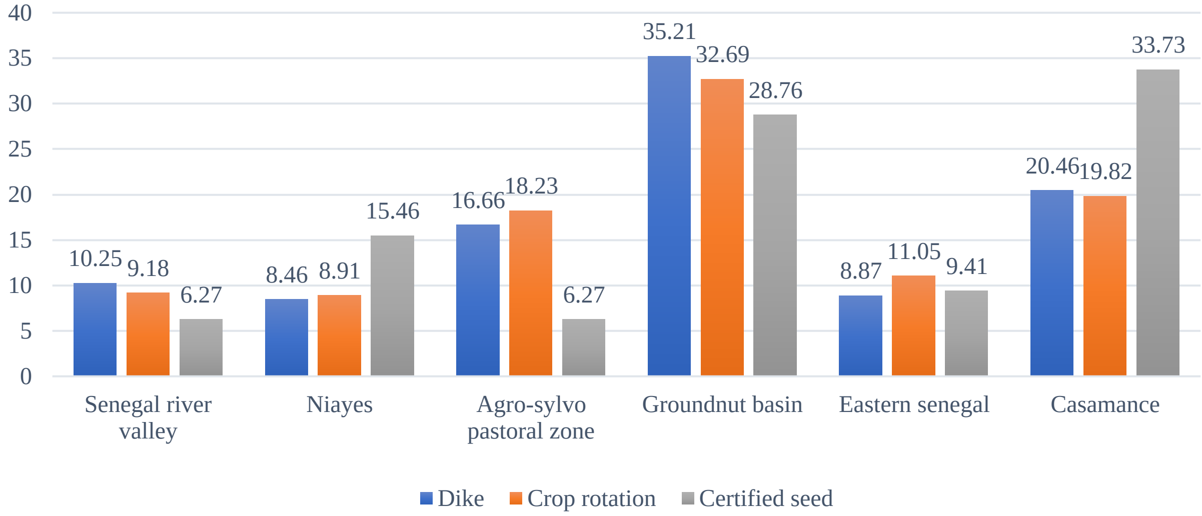
$$ATU = E\left(Y_{1i} \middle| A_i = 0\right) - E\left(Y_{2i} \middle| A_i = 0\right) = X_{1i}\left(\beta_1 - \beta_2\right) + \left(\sigma_{\mu_1\varepsilon} - \sigma_{\mu_2\varepsilon}\right)\lambda_{2i} \qquad (10)$$

Productivity is the ratio of the quantity produced (in kg) and the area (in hectares) of the farm. The survey provides information on the structure of production, including the quantities produced and the areas of agricultural holdings. This allows us to calculate agricultural productivity, which is different from total factor productivity, which would further incorporate measures of the efficiency of labor and the productivity of capital in the production process.

IV. RESULTS

Figure 2 shows adoption rates for the three specific resilience strategies selected for the analysis – construction of dikes, crop rotation, and use of certified seed – across agroecological zones. Farmers who have constructed dikes are most commonly found in the Groundnut Basin (35.2%) as are farmers who have implemented crop rotation (32.7%). Farmers who have adopted certified seeds are most common in the Casamance area (33.7%) and the Groundnut Basin (28.8%), with smaller numbers (6-9%) in other zones.

Figure 2: Resilience strategies by agroecological zone.



Source: Authors

4.1 Descriptive statistics

Table 2 presents the mean and difference test of the means of the socio-economic variables by resilience strategy adoption status. The main dependent variable of interest – farmer productivity as proxied by crop yield per hectare – is measured in two ways: the minimum productivity reported by the farmer for a given plot, and the maximum productivity reported for that same plot.

Farmers who built dikes report lower productivity on average than those who did not. The minimum productivity of farmers who built dikes is 212.28 kg/ha lower than that of farmers who did not ($p<0.050$), with no significant difference in maximum productivity. Farmers who built dikes are less likely to be female-headed households, and more likely to be married. They are also younger on average, and more likely to have no formal education ($p<0.050$). Farmers who built dikes on average have greater farm area than those who did not, with a significant difference of 0.33 hectares ($p<0.001$). In terms of farm management practices, farmers who have built dikes are more likely to purchase seed on the local market, and less likely to purchase with subsidies with partners or from specialized firms. There are also significant differences between farmers who built dikes and those who did not use of manual work (more common on farms with dikes), animal-drawn work (less common with dikes) and use of mineral inputs (less common with dikes). Finally, the construction of dikes also varies by agroecological zone.

Farmers who have adopted crop rotation similarly report lower productivity than those who have not adopted this resilience strategy. Specifically, the minimum productivity of farmers who have implemented crop rotation is 194.26 kg/ha lower ($p<0.001$) and the maximum productivity is 331.36 kg/ha lower ($p<0.001$). Farmer with a crop rotation system have fewer members in their household on average compared to those who have not, with no meaningful differences across gender of the household head. On average, the age of farmers who have set up a crop rotation system is roughly 1 year higher than that of farmers who have not ($p<0.001$), and though the large majority of farmers are married, those engaged in crop rotation are on average more likely to be married. In constrast to dikes which were more common among those farmers with no formal education, those farmers engaged in crop rotation are more likely to have at least some primary or secondary level educationand also more likely to have received training in agriculture. In terms of plot size, farmers who have set up a crop rotation system on average have more land than those who have not, with a significant difference of 0.55 hectares (p<0.001). Patterns for farm management strategies, largely mirror the patterns observed for adopters versus non-adopters of dikes – however we note that farmers using crop rotation are more likely than non-adopters to use organic fertilizers and mineral fertilizers, and also more likely to purchase seed with support of state subsidies. Adoption of crop rotation also varies significantly by agroecological zone.

Patterns among farmers who adopted certified seeds versus non-adopters differ notably from the other resilience strategies examined. First, adopters have higher average minimum and maximum crop yields than those who did not adopt certified seeds, though the differences are not statistically significant. Farmers who adopted certified seed are also more likely to be in female-headed households (p<0.100), and less likely to be married (p<0.100). We again see significant differences in use of this resilience strategy by education, with farmers with no formal education much less likely to adopt certified seed (p<0.001). Speaking Wolof is also positively associated with adopting certified seed (though this was not significant for either of the other resilience strategies). Among farm characteristics, farmers who adopted certified seed had larger plots on average than those who did not (p<0.001); they were also more likely to use motorized equipment (p<0.001) and mineral fertilizers (p<0.001), perhaps reflecting certified seed's tendency to be used as part of a "package" of modern inputs. Not surprisingly, there was a significant difference in seed purchasing between farmers who adopted certified seeds and those who did not, with farmers using certified seed less likely to report sourcing seed from personal reserves or the local market (p<0.001)), and more likely to make use of seed subsidies or to purchase from specialized firms (p<0.001). As with the two previous resilience strategies, adoption of certified seed also varies significantly by agroecological zone.

Table 2: Descriptive statistics

Variables	Dikes			Crop rotation			Certified Seed		
	Yes	No	Difference	Yes	No	Difference	Yes	No	Difference
Dependent variables									
Minimum productivity (kg/ha)	627.73	840.02	212.28**	572.03	766.30	194.26***	743.04	645.61	-97.42
Maximum productivity (kg/ha)	944.97	1110.63	165.65	825.93	1157.30	331.36***	1042.88	958.21	-84.67
Household head characteristics									
Household size	8.28	8.21	-0.69	8.21	8.34	0.12*	8.14	8.28	0.13
Female head of household	10.67	15.49%	0.48***	10.92%	11.73%	0.008	13.94%	11.02%	-0.029*
Age of head of household (year)	52.38	53.49	1.10***	52.95	51.93	-1.01***	52.73	52.50	-0.22.58
Marital status	89.93	85.16%	0.47***	90.11%	88.31%	-0.017***	87.45%	89.52%	0.02*
Without school level	72.22	68.64%	0.36**	70.42%	73.76%	0.033***	66.81%	72.28%	0.054***
Primary level	14.20	15.41%	0.12	15.14%	13.26%	-0.018**	17.18%	14.09%	-0.03*
Secondary level	9.72	12.11%	0.23**	10.95%	8.71%	-0.022***	11.67%	9.86%	-0.018*
Higher level	2.21	2.42%	0.002	1.99%	2.56%	0.005**	1.72%	2.28%	0.005
Wolof language	19.69%	21.36%	0.16	20.28%	19.35%	-0.009	22.91%	19.62%	-0.032*
Agricultural training	3.32%	2.49%	-0.008	3.5%	2.84%	-0.006*	3.24%	3.22%	-0.0001
Area (ha)	1.36	1.02	-0.33***	1.55	0.99	-0.55***	1.58	1.29	-0.29***
Inputs									
Manual work	54.72%	83.62%	0.28***	44.46%	77.28%	-0.55***	56.64%	58.41%	0.017
Drawn work	77.88%	45.88%	-0.31***	87.35%	55.51%	0.32***	67.45%	74.55%	0.07***
Motorized work	0.22%	0.58%	0.03	0.13%	0.44%	-0.31***	1.08%	0.19%	-0.008***
Organic fertilizer	35.63%	38.03%	0.23	41.83%	27.79%	-0.14***	31.02%	36.37%	0.053*
Mineral fertilizer	24.81%	30.24%	0.05***	29.12%	20.44%	-0.086***	37.18%	24.41%	-0.12***
Seed origins									
Personal reserve	72.15%	70.33%	-0.01	71.20%	72.94%	0.017**	51.67%	73.77%	0.22***
Purchase on the local market	24.02%	18.79%	-0.05***	26.22%	19.46%	-0.067***	17.62%	23.90%	0.06***
Purchase with state subsidy	8.30%	8.88%	0.005	9.23%	7.17%	-0.02***	38.16%	5.67%	-0.32***
Purchase with patner subsidy	1.17%	2.79%	0.016***	1.14%	1.68%	0.005*	6.16%	0.94%	-0.05***
Purchase from specialized firms	0.64%	1.68%	0.01***	0.99%	0.47%	-0.005***	1.72%	0.68%	-0.01***
Agroecological zones									
Senegal River Valley	10.24%	9.54%	-0.007	9.17%	11.51%	0.023***	6.27%	10.51%	0.042***
Niayes	8.46%	21.80%	0.13***	8.91%	11.73%	0.028***	15.47%	9.61%	-0.058***
Agro-sylvopastoral Zone	16.66%	4.03%	-0.12***	18.22%	10.83%	-0.07***	6.27%	15.91%	0.09***
Groundnut Basin	35.20%	21.73%	-0.13***	32.68%	43.76%	0.02**	28.75%	33.99%	0.05*
Eastern Senegal	8.87%	16.37%	0.07***	11.05%	8.05%	-0.029***	9.4%	9.82%	0.0042
Casamance	20.46%	26.43%	0.05***	19.82%	23.07%	0.032***	33.72%	20.05%	-0.13***

Source: Authors; Note: ***<1%, **<5%, *<10%

5 Analysis of factors associated with adoption of resilience strategies

Table 3 summarizes factors associated with the decision to adopt a resilience strategy in the face of agricultural shocks. Many recent studies in sub Saharan Africa suggest farmers perceive significant changes in climate including rising temperatures, changes in humidity and reduced precipitation. Findings in Table 3 suggest, in the rainy season, farmers may choose to build dikes, rotate crops or use certified seeds in the hope of improving or maintaining the yield of their crop. In the rainy season, family farms in rural areas adopt assorted strategies in an effort to cope with climate variability such as variation in humidity, temperature and precipitation. Similarly, in the dry season, the probability of building dikes, rotating crops and using certified seeds decreases in the presence of humidity, while it increases in the presence of rainfall. Farmers being rational, they take into account the perception of climatic shocks in their agricultural decision-making. These results confirm those of Gbetibouo (2009) in the Limpopo basin in South Africa and of Koguia et al., (2021) which show that adaptation to climate change is an appropriate response to perceptions of climate shocks.

The probability of adopting the crop rotation strategy increases significantly with household size, as household size is often considered an indicator of farm household labor. In Senegal, family farms mostly use family labour, which is why the large size of the household would be a source of increased probability of adopting resilience strategies. These results are consistent with those of Diallo and Donkor, (2020) in Mali and those of Onyeneke (2020) in Nigeria, which show that household size is a relevant explanatory factor for resilience to agricultural shocks. The female sex, the age of the head of the household, the level of education of the head of the farmer, significantly increase the probability of rotting the crops; which shows that women farmers are more involved in agricultural activities in rural areas. Farmers acquire knowledge and experience with age, which allows them to confidently implement resilience strategies. Also, educated farmers have the ability to perform ex-post and ex-ante analyzes related to the perception of agricultural shocks in order to adopt specific resilience strategies to expected shocks. These analyzes are in line with those of Khanal et al. (2018b), who estimate that the level of education is positively correlated with the adoption of different types of adaptations. In addition, the mastery of the local language (Wolof) is necessary for the use of certified seeds because the extension bodies generally use the Wolof language to sensitize local farmers in order to reach not only a large layer, but also to draw their attention to climate variability and agricultural shocks.

The likelihood of adopting resilience strategies depends on the agro-ecological zones. The agro-sylvo-pastoral zone, groundnut basin, eastern Senegal and Casamance are positively favorable to the construction of dikes and crop rotation. While the agro-sylvo-pastoral zone and groundnut basin are negatively linked to the use of certified seeds. These results are in line with those found by Diallo and Donkor (2020) showing the importance of location in the adoption of adaptation strategies to climate shocks.

Table 3: Determinants of the decision to adopt resilience strategies

Variables	Measures	Dikes	Crop rotation	Certified Seed
Rainy season of the year 2017	Humidity	21.22 (6.90)***	31.84 (5.38)***	-32.54 (8.93)***
	Precipitation	3.70 (1.28)***	-3.58 (1.07)***	4.57 (1.93)***
	Temperature	38.24 (15.13)***	-63.29 (12.18)***	-108.92 (22.63)***
Dry season of the year 2017	Humidity	-16.18 (8.26)**	63.14 (6.63)***	47.65 (13.74)***
	Precipitation	1.37 (0.24)***	-0.70 (0.14)***	0.74 (0.21)***
	Temperature	-12.42 (30.70)	214.78 (25.86)***	134.59 (53.06)***
Rainy season of the year 2018	Humidity	7.20 (7.80)	-47.9 (6.00)***	-17.99 (11.36)
	Precipitation	-2.56 (1.12)***	2.07 (0.91)***	-2.78 (1.56)*
Dry season of the year 2018	Humidity	19.83 (7.72)***	-64.09 (6.07)***	-32.20(10.79)***
	Precipitation	-3.54 (0.57)***	0.27 (0.35)***	-2.89 (0.55)***
	Temperature	24.67 (21.98)	-170.98 (18.24)***	-70.19 (34.43)**
Household head characteristics	Household size	0.002 (0.005)	0.01 (0.00)***	-0.007 (0.005)
	Female	-0.036 (0.067)	0.13 (0.05)***	0.09 (0.07)
	Age	-0.004 (0.001)***	0.00 (0.00)***	0.00 (0.00)
	Marital status	-0.018 (0.06)	0.14 (0.05)***	-0.01 (0.08)
	No formal ed.	-0.061 (0.15)	0.15 (0.10)	0.00 (0.14)
	Primary level	-0.081 (0.16)	0.26 (0.11)***	0.00 (0.15)
	Secondary level	-0.13 (0.16)	0.35 (0.11)***	0.01 (0.15)
	Higher level	0.22 (0.19)	0.33 (0.13)***	-0.36 (0.19)*
	Wolof language	-0.10 (0.05)***	-0.04 (0.04)	0.15 (0.58)**
	Agric. training	0.05 (0.11)	-0.12 (0.07)	-0.01 (0.11)
Contraints	Sand / silt	0.17 (0.45)***	0.06 (0.03)**	-0.27 (0.05)***
	Loss of fertility	0.21 (0.4)***	0.44 (0.029)***	-0.14 (0.05)***
	Rains	1.02 (0.21)***	0.03 (0.087)	0.15 (0.15)
	Soil salinity	-0.11 (0.86)	0.40 (0.86)***	-0.25 (0.10)**
Inputs	Manual work	-0.32 (0.05)***	-0.63 (0.031)***	-0.43 (0.05)***
Seed origins	Personal reserve	-0.24 (0.42)***	-0.02 (0.03)	-0.19 (0.047)***
	State subsidy	-0.33 (0.06)***	0.09 (0.04)***	1.44 (0.054)***
Agroecological zone	Niayes	0.003 (0.09)	0.40 (0.07)***	0.55 (0.10)***
	Agro-sylvopastoral	0.46 (0.11)***	0.36 (0.06)***	-0.58 (0.11)***
	Groundnut Basin	0.35 (0.09)***	0.22 (0.05)***	-0.14 (0.09)
	Eastern Senegal	0.61 (0.14)***	0.85 (0.11)***	0.95 (0.22)***
	Casamance	0.41 (0.07)***	0.46 (0.06)***	0.67 (0.11)***
	Constant	-304.94 (75.93)***	138.33 (57.17)***	303.31 (84.81)***
Crop Rotation and Dike		0.066 (0.017)***		
Certified Seeds and Dike		-0.12 (0.026)***		
Certified Seeds and Crop Rotation		0.012 (0.023)		
Likelihood ratio test of $rho_{ij}=0$		37.23 ***		

Note: ( ) standard dev ; ***<1%, **<5%, *<10%

Source: Authors

The correlation coefficients between the different resilience strategies taken two by two are positively significant in two out of three cases, showing a positive interaction between some resilience strategies. The construction of dikes has a positive and significant association with crop rotation (rho 21). Similarly, the construction of dikes has a negative and significant association with the adoption of certified seeds (rho 31). Overall, farmers are able to combine the two strategies of building dikes and other types of resilience strategies (crop rotation and improved seeds). The correlation between crop rotation and other types of resilience strategies is positive and significant. This shows that crop rotation promotes the adoption of certified seeds (rho 32). Thus, in the presence of agricultural and climatic hazards, farmers in rural areas in Senegal adopt the crop rotation strategy combined with the use of certified seeds as resilience strategies.

6 Impact of resilience strategies on agricultural productivity

To analyze the impact of resilience strategies to agricultural shocks on agricultural productivity, we used the endogenous switching regression model to take into account the problem of endogeneity in examining the impact of resilience strategies on agricultural productivity. agricultural productivity. The results presented in Table 4 explain the endogenous switching of production functions. Signs and significances of the covariance terms ρ_1 and ρ_2 constitute an interesting result. The results show that the covariance terms for non-resilients are statistically significant in most models, indicating that self-selection occurred within the framework of resilience. Thus, the adoption of resilience strategies to minimize the impact of agricultural shocks does not have the same effect on non-adopters, if they choose to adopt resilience strategies. Moreover, the differences in the coefficients of the productivity equations between the farmers who adopted them and those who did not suggest the presence of heterogeneity in the sample.

In line with the economic literature, farmers who speak most of the time in the Wolof language significantly reduce the agricultural productivity of those who have respectively built dikes, rotated crops and adopted certified seeds by 13%, 19% and 25% respectively. They still reduce the agricultural productivity of those who have not terminated. Despite the awareness and popularization of certain resilience strategies, farmers are still attached to their cultures and ancestral methods and therefore are reluctant to adopt certain resilience strategies. Manual labor or hiring labor reduced the agricultural productivity of those who built dikes by 7%, by 17% for those who rotated crops and by 118% for those who adopted seeds. certified. Thus, the hiring of unskilled labor contributes to the reduction of productivity due to the non-mastery by these workers of good farming practices. These results contradict those found by Onyeneke (2020); Diallo and Donkor (2020); Khanal et al., (2018b) who show that the labor factor significantly increases agricultural productivity in Nigeria, Mali and Nepal respectively.

The use of agricultural inputs by farmers contributes to the increase in agricultural productivity by 22% for those who have built dikes, 38% for those who have rotated crops and 31% for those who have adopted certified seeds. . These results are consistent with the work of Khanal et al. (2018b), which shows that the use of fertilizers increases the agricultural productivity of all farmers who adopt adaptation strategies. Moreover, the increase in productivity in this case is justified by the fact that the quantities of fertilizer dosage in the fields have been respected by the farmers. Farmers living in Casamance contribute significantly to the reduction of agricultural productivity by 76%, 105% and 198% for those who have built dikes, rotated crops and adopted certified seeds respectively. Thus, farmers in Casamance are less reluctant to adopt resilience strategies. This is justified by a more favorable environment for agriculture compared to other areas.

Climatic and agricultural shocks drastically impact agricultural production. In this regard, the silting up of fields contributes significantly to the increase in agricultural productivity of those who have built dikes, rotated crops and adopted certified seeds by 11%, 21% and 37% respectively. As for soil salinity, it considerably increases the agricultural productivity of those who have built dams, rotated crops and adopted certified seeds by 39%, 6% and 118% respectively. Thus, in the face of climatic shocks, farmers are led to adopt resilience strategies in order to cope with these various shocks.

Table 4: Impact of resilience strategies on agricultural productivity

Variables	Designations	Dyke			Crop rotation			Certified Seed		
		Selection	Resilient	Non- Resilient	Selection	Resilient	Non- Resilient	Selection	Resilient	Non- Resilient
Rainy season of the year 2017	Humidity	21(6,67) ***	-24,74(7,1) ***	61,1(20,79) **	20,5(4,9) ***	-29,6(9,4) ***	1,74(12,35)	-29,6(9,1) **	-1,34(30,82)	-20,5(6,7) ***
	Precipitation	3,13(1,28) *	3,89(1,52) ***	26,15(4,22) ***	-1,91(1,02) *	3,51(1,97) *	7,1(2,5)***	4,86(1,93) **	-21,8(6,4) ***	7(1,36) ***
	Temperature	28,9(15,5) *	-73,3(17,8)***	-75,18(51,75)	-66,2(11,4)***	-165(23,3)***	-193(28)***	-110,3(23)***	217,1(78)***	-85,7(16,8)***
Dry season of the year 2017	Humidity	-9,56(8,24)	7,97(10,12)	83,53(28,02) **	55,19(6,4)***	47,5(13,8)***	111(16)***	49,63(14,4) **	-219(48,3)***	24,96(9,2)***
	Precipitation	0,91(0,2)***	-0,68(0,17)***	1,44(0,86)*	-0,66(0,12)***	-1,3(0,22)***	-1,9(0,3)***	0,75(0,22) **	0,19,66(0,72)	-1,3(0,17) ***
	Temperature	11,21(30,48)	189(40,5)***	666,3(97,8)***	192,8(24)***	282(51,95)***	593(61)***	140,4(55,5)**	-567(182)***	264(37,8)***
Rainy season of the year 2018	Humidity	4,55(7,81)	7,01(8,30)	-75,83(25,4)**	-38,23(5,6)***	-30,5(10,6)***	-64,4(14)***	-22,5(11,4) **	168,6(38)***	-9,47(7,79)
	Precipitation	12,21(7,67)	-4,29(1,31)***	-22,51(3,7)***	2,07(0,86)**	-2,98(1,72)*	-5,7(2)***	-2,98(1,56)*	16,69(5,37) **	-5,8(1,16)***
Dry season of the year 2018	Humidity	-2,25(1,12)*	-23,46(8,4)***	-57,53(27,1)**	-57,22(5,6)***	-62,7(10,9)***	-119(14)***	-32,55(11,5)**	120,7(35)***	-35,58(7,9)***
	Precipitation	-2,82(0,5)***	3,41(0,39)***	-5,20 (2,10) **	-0,08(0,31)	4,68(0,5)***	2,52(0,7)***	-3,09(0,55)***	8,44(1,77)***	3,44(0,38)***
	Temperature	7,19(21,67)	-164,5(26)***	-425(70,8)***	-155,3(17)***	-234,4(34)***	-466(43)***	-71,06(36,63)*	243,5(114,6)*	-211,5(24)***
Household head characteristics	Age	3,74(1,92)*	2,58(1,80)	11,69(5,92)**	0,13(1,3)	2,52(2,14)	-1,03(3,28)	-5,06(1,98)**	-0,48(5,09)	3,94(1,85)**
	Age ²	-0,51(0,25)*	-0,34(0,23)	-1,57(0,77)**	0,006(0,17)	-0,29(0,28)	0,17(0,43)	0,66(0,26)**	0,03(0,67)	-0,52(0,24)*
	Size of household	-0,24(0,13)*	0,13(0,12)	-0,18(0,43)	0,21(0,08)**	0,07(0,16)	0,6(0,22)**	0,14(0,14)	0,16(0,39)	0,16(0,12)
	Taille²	0,07(0,038)*	-0,042(0,036)	0,043(0,12)	-0,05(0,025)*	-0,02(0,04)	-0.15(0,06)*	-0,05(0,04)	-0,04(0,11)	-004(0,036)
	Female sex	0,04(0,067)	0,09(0,07)	0,11(0,20)	-0,07(0,05)	0,0001(0,08)	0,006(0,12)	-0,1(0,07)	0,22(0,22)	-0,07(007)
	Marital status	-0,008(0,06)	-0,15(0,07)**	0,07(0,20)	0,05(0,05)	-0,17(0,09)*	0,15(0,12)	0,01(0,08)	0,11(0,37)	-0,13(0,07)*
	Without school level	-0,05(0,15)	-0,01(0,14)	-0,06(0,49)	0,16(0,1)	-0,09(0,18)	0,40(0,25)	0,006(0,14)	-0,36(0,38)	0,12(0,14)
	Primary	-0,09(0,16)	-0,01(0,15)	-0,49(0,50)	0,26(0,1)**	-0,04(0,18)	0,49(0,26)*	-0,0003(0,15)	0,004(0,39)	0,11(0,15)
	secondary	-0,13(0,16)	0,18(0,15)	-0,19(0,50)	0,33(0,1)**	0,23(0,19)	0,82(0,26)**	0,017(0,15)	-0,14(0,62)	0,31(0,15)**
	Higher	0,10(0,19)	0,12(0,18)	0,43(0,60)	0,2(0,12)	0,38(0,23)	0,5(0,32)	-0,34(0,2)*	-0,16(0,18)	0,26(0,18)
	Wolof language	-0,12(0,05)**	-0,13(0,053)**	-0,3(0,16)*	-0,018(0,37)	-0,19(0,06)***	-0,09(0,097)	0,15(0,05)**	-0,25(0,32)	-0,16(0,05)***
	Agricultural training	0,02(0,11)	-0,02(0,10)	-0,15(0,34)	-0,09(0,073)	-0,07(0,12)	-0,3(0,19)	-0,023(0,11)	-0,37(0,18)*	-0,04(0,1)
Contraints	Sand encroachement	0,17(0,04)***	0,11(0,05)**	0,33(0,13)**	0,05(0,034)*	0,21(0,06)***	-0,11(0,8)	-0,29(0)***	0,37(0,18)**	0,03(0,05)
	Loss of fertility	0,18(0,04)***	-0,4(0,3)***	0,05(0,14)	0,36(0,02)***	-0,03(0,4)***	0,26(0,07)***	-0,1(0,4)**	-0,36(0,1)**	-0,4(0,3)*
	Rains	0,97(0,2)***	-0,6(0,1)***	0,86(0,82)	-0,024(0,08)	-0,76(0,1)***	-0,68(0,2)***	0,09(0,15)	-0,37(0,49)	-0,7(0,1)*
	Soil salinity	-0,15(0,08)*	0,3(0,09)***	0,07(0,25)	0,34(0,06)***	0,06(0,14)	1,05(0,15)***	-0,2(0,1)**	1,18(0,3)***	0,34(0,9)***
Inputs	Manual work	-0,3(0,04)***	-0,07(0,4)**	0,11(0,17)	-0,6(0,03)***	-0,17(0,06)**	-0,8(0,08)***	-0,4(0,5)**	1,18(0,24)***	-0,05(0,04)
Agroecological zone	Eastern Senegal	-0,59(0,6)	-0,23(0,15)	2,24(0,38)***	-1,03(0,43)**	0,53(0,2)**	0,75(0,25)**	1,48(0,95)***	-4,56(0,8)***	0,25(0,14)*
	Casamance	-0,82(0,6)	-0,7(0,7)***	0,15(0,21)	-1,62(0,4)***	-1(0,11)***	-0,32(0,11)**	1,15(0,93)	-1,98(0,3)***	-0,8(0,7)***
	Senegal valley	-1,2(0,59)**			-1,91(0,4)***			0,5(0,93)		
	Niayes	-0,94(0,59)			-1,6(0,42)***			1,04(0,92)		
	Agro-sylvopastoral zone	-0,65(0,6)			-1,6(0,42)***			-0,06(0,94)		
	Groundnut basin	-0,89(0,6)			-1,67(0,4)***			0,33(0,93)		
Seed origins	Llocal purchase	0,28(0,06)***	0,045(0,06)	0,41(0,21)*	0,13(0,043)**	0,05(0,06)	0,22(0,11)*	-0,14(0,06)**	0,27(0,16)	0,04(0,06)
	Personal resserve	-0,006(0,06)	0,22(0,058)***	-0,30(0,19)	0,12(0,04)**	0,38(0,07)***	0,028(0,1)	-0,2(0,05)***	0,31(0,16)*	0,26(0,06)***
	Purchase with state subsidy	-0,2(0,06)***	0,09(0,06)	-0,49(0,21)**	0,18(0,04)***	0,19(0,07)**	0,17(0,12)	1,4(0,06)***	-0,53(0,56)	-0,06(0,1)
Constant		-283,6(75,6)*	292,81(71,1)***	-618,8(264,9)**	177,52(51,4)***	699,04(96,6)***	510(129,2)***	301(88,3)***	23,3(275,08)	261,9(71,4)***
σ			0,55(0,007)***	0,98(0,05)***		0,53(0,009)***	0,95(0,10)***		0,54(0,10)***	056(0,007)***

ρ		0,04(0,04)	1,6(0,13)***		0,09(0,06)	1,8(0,047)***		-0,53(0,32)	-0,02(0,09)

Table 5 presents predicted agricultural productivity under real and counterfactual conditions. Cells (a) and (b) for each resilience strategy represent the observed agricultural productivity of the sample. Cell (c) represents the predicted agricultural productivity per hectare of the different resilience strategies if farmers had decided not to adopt them and cell (d) represents the predicted agricultural productivity per hectare of the non-resilients of the different resilience practices. they had decided to adopt them. The last column shows the effect of various resilience strategies on agricultural productivity, which is calculated as the difference between columns 3 and 4. Thus, we find that the adoption of various resilience strategies to agricultural shocks has a statistically significant impact on agricultural productivity; that is, the construction of dikes, crop rotation and adoption of certified seeds are statistically significant for agricultural productivity.

Farmers who built dikes produced 247.26 kg/ha compared to 432.15 kg/ha for farmers who did not. However, this simple comparison can be misleading and lead researchers to conclude that, on average, those who built dikes produced 42.78% (or 184.89 kg/ha) less than those who did not. do. Rainwater retention bunds help prevent field flooding, erosion, leaching and soil nutrient depletion. These results have not yet been discussed in the literature. Farmers who rotated crops produced 264.82 kg/ha compared to 208.62 kg/ha for farmers who did not. Farmers who did rotate crops produced 56.2 kg/ha (or 26.93%) more than those who did not rotate crops. These results are consistent with those obtained by Onyeneke (2020), Diallo and Donkor (2020) and Khanal et al., (2018b) in their respective countries, which show that farmers who used resilience methods such as crop rotation produced 7% more than those who did not.

Similarly, the agricultural productivity of farmers who have adopted certified seeds is about 350.65 kg/ha against 201.87 kg/ha for farmers who have not adopted this variety of seeds. Farmers who actually adopted Certified seeds produced about 148.78 kg/ha, an increase of 73.7% compared to those who did not. In order to increase yields in the face of the scarcity of rainfall, farmers are forced to sow improved (certified) seeds. These results confirm those of Onyeneke (2020) in Nigeria and Diallo and Donkor (2020) in southern Mali, who found that the use of seeds with short germination times increases agricultural productivity and household food security. . In addition, farmers who built dikes would have produced about 195.56 kg/ha more if they had not built dikes. These results are in line with those of many other studies (Di Falco et al., 2011; Khanal et al., 2018b; Diallo and Donkor 2020; Dessalegn et al., 2022) and opposite to the study of Quan et al., (2019) who conclude that certain strategies such as soil and water conservation and irrigation have a significantly negative impact on crop yields in China.

Similarly, those who rotated the crops would have produced 20947.39 kg/ha less if they had not rotated the crops. Finally, farmers who adopted Certified seed would have produced 5831.67 kg/ha less if they had not adopted Certified seed. On the other hand, farmers who did not build dikes would have produced 281.87 kg/ha less if they had built dikes. Also, those who did not rot would have produced 46.32 kg/ha more if they had. On the other hand, those who did not adopt certified seeds would have produced 588780.4 kg/ha more if they had adopted it. The results of this study are consistent with those of many other studies (Di Falco et al., 2011; Khanal et al., 2018b; Diallo and Donkor 2020; Dessalegn et al., 2022). They also show that if households do not adapt, they will lose 20% of their production. And a 35% increase in the production of non-adaptive households if they adapt to climate change.

Table 5: Average Productivity: Treatment Effect

Sub-sample		With adoption	Without adoption	Treatment effect
Construction of dikes	Adopters	**(a)** 247,26	**(c)** 51,69	TT= 195,56***
		(1,63)	(0,66)	(1,6)
	Non-adopters	**(d)** 150,27	**(b)** 432,15	TU= - 281,87***
		(2,71)	(17,83)	(16,75)
Crop rotation	Adopters	**(a)** 264,82	**(c)** 21212,22	TT= -20947,39***
		(2,24)	(205,02)	(203,52)
	Non-adopters	**(d)** 254,94	**(b)** 208,62	TU= 46,32***
		(2,64)	(1,73)	(2,59)
Certified seed	Adopters	**(a)** 350,65	**(c)** 6182,32	TT= -5831,67***
		(14,86)	(167,42)	(156,97)
	Non-adopters	**(d)** 588982,3	**(b)** 201,87	TU= 588780,4***
		(53634,62)	(1,1)	(53634,67)

Note : (.) standard dev ; ***<1%, **<5%, *<10.
Source: Authors

8. Heterogeneity analysis according to agro-ecological zones

8.1. Construction of dikes according to agro-ecological zones

Table 6 presents the predicted agricultural productivity under real and counterfactual conditions in the different agro-ecological zones of Senegal.

To this end, farmers in the Senegal Valley who built dikes produced 463.47 kg/ha against 1989,92 kg/ha for farmers who did not. However, this simple comparison can be misleading and lead researchers to conclude that, on average, those who built dikes produced -1526.59 kg/ha, or 76.71% less than those who did not. As for farmers in the Niayes area, they produced 205.98 kg/ha against 145.93 kg/ha for those who did not. Thus, farmers in the Niayes area who actually built dikes produced 60.05 kg/ha, or 41.14% more than those who did not. For farmers in the Sylvio-pastoral zone who built dikes, they produced 199.41 kg/ha against 118.04 kg/ha for farmers who did not. Farmers in the Sylvio-pastoral zone who actually built dikes produced 81.37 kg/ha, or 68.93% more than those who did not. Concerning the Groundnut Basin farmers who built dikes, they produced 195.92 kg/ha against 229.64 kg/ha for the farmers who did not. Farmers in the Groundnut Basin who actually built dikes produced 33.72 kg/ha, or 14.68% more than those who did not. As for farmers in the eastern Senegal zone, they produced 109.18 g/ha against 134.63 kg/ha for farmers who did not build dikes. Farmers in the eastern Senegal zone who built dikes actually produced 25.45 kg/ha, or 18.9% less than those who did not. Similarly, farmers in Casamance who built dikes produced 253.84 kg/ha against 630.26 kg/ha for those who did not build dikes. Thus, farmers in Casamance who actually built dikes produced 376.42 kg/ha, or 59.72% less than those who did not. Rainwater retention bunds help prevent field flooding, erosion, leaching and soil nutrient depletion. These results have not yet been discussed in the literature.

In addition, farmers in the Senegal Valley who built dikes would have produced about 1037.23 kg/ha more if they had not built dikes. Those in the Niayes area who built dikes would have produced 199.97 kg/ha more if they had not built dikes. Similarly, farmers in the Sylvio-pastoral zone who built dikes would have produced 197.45 kg/ha more if they had not built dikes. For farmers in the Groundnut Basin who built dikes, they would have produced 187.93kg/ha more if they had not built dikes. As for farmers in Eastern Senegal who built dikes, they would have produced 19,192.02 kg/ha more if they had not built dikes. Finally, farmers in Casamance who built dikes would have produced 226.19kg/ha less if they had not built dikes. These results are in line with those found by Quan et al., (2019) who conclude that certain strategies such as soil and water conservation and irrigation have a significantly negative impact on crop yields in China. All this is explained through the poor adaptation of some farmers.

On the other hand, farmers in the Senegal Valley who did not build a dike would have produced 1812.48 kg/ha less if they had built dikes. Also, those in the Niayes area who did not build a dike would have produced 1959.18 kg/ha less if they had built dikes. For farmers in the Sylvio-pastoral zone who did not build a dike, they would have produced -15.69 kg/ha less if they had built dikes. Unlike the Groundnut basin farmers who did not build a dike, they would have produced 18.97 kg/ha more if they had built dikes. Regarding farmers in Eastern Senegal who did not build a dike, they would have produced 30.03 kg/ha less if they had built dikes. For farmers in Casamance who did not build a dike, they would have produced 430.71 kg/ha less if they had built dikes. The results of this study are consistent with those of many other studies (Di Falco et al., 2011; Khanal et al., 2018b; Diallo and Donkor 2020; Dessalegn et al., 2022). They also show that if households do not adapt, they will lose 20% of their production. And a 35% increase in the production of non-adaptive households if they adapt to climate change.

8.2. Crop rotation by agro-ecological zone

The table below presents the predicted agricultural productivity under real and counterfactual conditions in the different agro-ecological zones of Senegal. It should also be noted that crop rotation has a significant impact on agricultural productivity.

To this end, farmers in the Senegal Valley who rotated crops produced 476.14 kg/ha against 387.3 kg/ha for farmers who did not. However, this simple comparison can be misleading and lead researchers to conclude that, on average, those who did indeed burp crops produced 88.84 kg/ha, or 22.93 % more than those who did not. As for the farmers in the Niayes area who rotated the crops, they produced 315.45 kg/ha against 153.9 kg/ha for those who did not. Thus, farmers in the Niayes area who actually rotated crops produced 161.55 kg/ha, or 104.97% more than those who did not. For farmers in the Sylvio-pastoral zone who rotated crops, they produced 212.42 kg/ha against 310.72 kg/ha for farmers who did not. Farmers in the Sylvio-pastoral zone who did rotate crops produced 98.3 kg/ha, or 31.63% less than those who did not. Concerning the Groundnut Basin farmers who rotated the crops, they produced 259.94 kg/ha against 311.12 kg/ha for the farmers who did not. Farmers in the Groundnut Basin who effectively rotated crops produced 51.18 kg/ha, or 16.45% less than those who did not. As for the farmers in the eastern Senegal zone who rotated the crops, they produced 118.04 g/ha against 107.67 kg/ha for the farmers who did not rotate the crops. Farmers in the eastern Senegal zone who rotated crops actually produced 10.37 kg/ha, or 9.63% more than those who did not. Similarly, farmers in Casamance who rotated crops produced 190.7 kg/ha compared to 183.32 kg/ha for those who did not rotate crops. Thus, farmers in Casamance who actually rotated crops produced 7.38 kg/ha, or 4.02% more than those who did not. These results are consistent with those obtained by Onyeneke (2020), Diallo and Donkor (2020) and Khanal et al., (2018b) in their respective countries, which show that farmers who used resilience methods such as crop rotation produced 7% more than those who did not.

In addition, farmers in the Senegal Valley who rotated the crops would have produced about 337.58 kg/ha less if they had not rotated the crops. Those in the Niayes area who rotated the crops would have produced 282.3 kg/ha less if they had not rotated the crops. Similarly, farmers in the Sylvio-pastoral zone who rotated the crops would have produced 114.56 kg/ha less if they had not rotated the crops. For farmers in the Groundnut Basin who rotated the crops, they would have produced 162.97 kg/ha less if they had not rotated the crops. As for the farmers in Eastern Senegal who rotated the crops, they would have produced 84.19 kg/ha less if they had not rotated the crops. Finally, farmers in Casamance who rotated the crops would have produced 132.61 kg/ha less if they had not rotated the crops.

On the other hand, farmers in the Senegal Valley who did not rot the crops would have produced 0.42 kg/ha more if they had rotted the crops. Also, those in the Niayes area who did not rotate the crops would have produced 7.38 kg/ha more if they had rotated the crops. Unlike farmers in the Sylvio-pastoral zone who did not rotate the crops, they would have produced -120.95 kg/ha less if they had rotated the crops. Similarly, farmers in the Groundnut Basin who did not rot the crops would have produced -51.86 kg/ha less if they had rotted the crops. For farmers in Eastern Senegal who did not rot the crops, they would have produced 1.72 kg/ha more if they had rotted the crops. For farmers in Casamance who did not rot the crops, they would have produced 15.92 kg/ha more if they had rotted the crops. The results of this study are consistent with those of many other studies (Di Falco et al., 2011; Khanal et al., 2018b; Diallo and Donkor 2020; Dessalegn et al., 2022). They also show that if households do not adapt, they will lose 20% of their production. And a 35% increase in the production of non-adaptive households if they adapt to climate change.

8.3. Seeds certified by agro-ecological zone

The table below presents the predicted agricultural productivity under real and counterfactual conditions in the different agro-ecological zones of Senegal. It should also be noted that the adoption of certified seeds has a significant impact on agricultural productivity.

To this end, farmers in the Senegal Valley who adopted certified crops produced 609.45 kg/ha against 408.41 kg/ha for farmers who did not. However, this simple comparison can be misleading and lead researchers to conclude that, on average, those who actually adopted the certified crops produced 201.04 kg/ha, or 49.22% more than those who did not. not done. As for farmers in the Niayes area who adopted certified crops, they produced 500.58 kg/ha against 231.09 kg/ha for those who did not. Thus, farmers in the Niayes area who actually adopted certified crops produced 269.49 kg/ha, or 116.61% more than those who did not. For farmers in the Sylvio-pastoral zone who adopted certified crops, they produced 203.4 kg/ha against 190.93 kg/ha for farmers who did not. Farmers in the Sylvio-pastoral zone who actually adopted certified crops produced 12.47 kg/ha, or 6.5% more than those who did not. Concerning the Groundnut Basin farmers who adopted certified crops, they produced 279.37 kg/ha against 207.71 kg/ha for farmers who did not. Groundnut Basin farmers who actually adopted certified crops produced 71.66 kg/ha, or 34.5% more than those who did not. As for farmers in the eastern Senegal zone who adopted certified crops, they produced 295.63 kg/ha against 79.71 kg/ha for farmers who did not adopt certified crops. Farmers in the eastern Senegal zone who actually adopted certified crops produced 215.92 kg/ha, or 270.88% more than those who did not. Similarly, farmers in Casamance who adopted certified crops produced 375.88 kg/ha against 202.52 kg/ha for those who did not adopt certified crops. Thus, farmers in Casamance who actually adopted certified crops produced 173.36 kg/ha, or 85.6% more than those who did not. These results are consistent with those obtained by Onyeneke (2020), Diallo and Donkor (2020) and Khanal et al., (2018b) in their respective countries, which show that farmers who used resilience methods such as crop rotation produced 7% more than those who did not.

In addition, farmers in the Senegal Valley who adopted certified crops would have produced about 278.87 kg/ha less if they had not adopted certified crops. Those in the Niayes area who adopted certified crops would have produced 274.4 kg/ha less if they had not adopted certified crops. Similarly, farmers in the Sylvio-pastoral zone who adopted certified crops would have produced 11.37 kg/ha more if they had not adopted certified crops. For farmers in the Groundnut Basin who have adopted certified crops, they would have produced 230.98 kg/ha less if they had not adopted certified crops. As for farmers in Eastern Senegal who adopted certified crops, they would have produced 276.31 kg/ha more if they had not adopted certified crops. Finally, farmers in Casamance who adopted certified crops would have produced 238.44 kg/ha less if they had not adopted certified crops.

In addition, farmers in the Senegal Valley who did not adopt certified crops would have produced 38,931.6 kg/ha more if they had adopted certified crops. Also, those in the Niayes area who did not adopt certified crops would have produced 10,235.24 kg/ha more if they had adopted certified crops. Unlike farmers in the Sylvio-pastoral zone who did not adopt certified crops, they would have produced 25,3208.7 kg/ha less if they had adopted certified crops. As for farmers in the Groundnut Basin who did not adopt certified crops, they would have produced 6713.54 kg/ha more if they had adopted certified crops. Regarding farmers in Eastern Senegal who did not adopt certified crops, they would have produced 43.86 kg/ha less if they had adopted certified crops. For farmers in Casamance who did not adopt certified crops, they would have produced 16.16 kg/ha less if they had adopted certified crops.

The results of this study are consistent with those of many other studies (Di Falco et al., 2011; Khanal et al., 2018b; Diallo and Donkor 2020; Dessalegn et al., 2022). They also show that if households do not adapt, they will lose 20% of their production. And a 35% increase in the production of non-adaptive households if they adapt to climate change.

Table 6: Impact of resilience strategies by agro-ecological zone.

Agroecological zones	Sous échantillon	Construction of dikes			Crop rotation			Seed certified		
		suitable	Not suitable	Treatment effect	suitable	Not suitable	Treatment effect	suitable	Not suitable	Treatment effect
Senegal valley	Adapted operator	(a) 463,47 (2,3)	(c) 1500,71 (13,2)	TT= -1037,23*** (13,98)	(a) 476,14 (3,71)	(c) 138,55 (0,82)	TT= 337,58*** (5,6)	(a) 609,45 (3,1)	(c) 330,57 (1,27)	TT= 278,87*** (0,49)
	Unsuitable operator	(d) 177,43 (3,24)	(b) 1989,92 (32,15)	TU= -1812,48*** (32,75)	(d) 387,77 (1,08)	(b) 387,35 (1,53)	TU= 0,42 (6,1)	(d) 389725,1 (201,53)	(b) 408,41 (0,2)	TU= 389316,6*** (2015,61)
Niayes	Adapted operator	(a) 205,98 (0,72)	(c) 6,01 (0,2)	TT= 199,97*** (0,7)	(a) 315,45 (1,47)	(c) 33,15 (0,33)	TT= 282,3*** (1,28)	(a) 500,58 (4,57)	(c) 226,17 (1,02)	TT= 274,4*** (29,44)
	Unsuitable operator	(d) 2105,12 (49,31)	(b) 145,93 (4,3)	TU= 1959,18*** (45,37)	(d) 161,29 (71,47)	(b) 153,9 (146,07)	TU= 7,38 (5,63)	(d) 10466,33 (12714,75)	(b) 231,09 (1,74)	TU= 10235,24 (40,34)
Agrosylvopastoral	Adapted operator	(a) 199,41 (0,71)	(c) 1,96 (0,014)	TT= 197,45*** (0,7)	(a) 212,42 (1,6)	(c) 97,86 (0,64)	TT= 114,56*** (1,3)	(a) 203,4 (122,96)	(c) 214,78 (122,19)	TT= -11,37 (13,62)
	Unsuitable operator	(d) 102,35 (78,28)	(b) 118,04 (167,81)	TU= -15,69*** (14,75)	(d) 189,77 (101,62)	(b) 310,72 (195,63)	TU= -120,95*** (5,73)	(d) 253399,6 (585,58)	(b) 190,93 (0,1)	TU= 253208,7*** (585,67)
Groundnut basin	Adapted operator	a) 195,92 (0,77)	(c) 7,98 (0,01)	TT= 187,93*** (0,78)	a) 259,94 (1,08)	(c) 96,97 (0,7)	TT= 162,97*** (2,55)	a) 279,37 (7,5)	(c) 48,39 (0,81)	TT= 230,98*** (7,02)
	Unsuitable operator	(d) 248,62 (0,05)	(b) 229,64 (0,95)	TU= 18,97*** (0,01)	(d) 259,26 (1,17)	(b) 311,12 (2,1)	TU= -51,86*** (5,9)	(d) 6921,26 (24,82)	(b) 207,71 (0,69)	TU= 6713,54*** (4,56)
Eastern Senegal	Adapted operator	a) 109,18 (64,35)	(c) 19301,21 (166393,3)	TT= -19192,02*** (5650,7)	a) 118,04 (102,56)	(c) 33,85 (19,45)	TT= 84,19*** (3,27)	a) 295,63 (81,79)	(c) 19,31 (0,28)	TT= 276,31 (81,73)
	Unsuitable operator	(d) 104,59 (72,23)	(b) 134,63 (116,82)	TU= -30,03*** (4,19)	(d) 109,39 (77,75)	(b) 107,67 (51,41)	TU= 1,72 (2,51)	(d) 35,84 (2,01)	(b) 79,71 (0,29)	TU= -43,86*** (1,94)
Casamance	Adapted operator	a) 253,84 (2,16)	(c) 27,65 (0,29)	TT= 226,19*** (2,27)	a) 190,7 (117,95)	(c) 58,09 (22,22)	TT= 132,61*** (3,03)	a) 375,88 (17,63)	(c) 137,44 (4,17)	TT= 238,44*** (10,79)
	Unsuitable operator	(d) 199,54 (5,59)	(b) 630,26 (42,04)	TU= -430,71*** (43,66)	(d) 199,25 (116,6)	(b) 183,32 (49,14)	TU= 15,92*** (3,38)	(d) 186,35 (2,83)	(b) 202,52 (1,29)	TU= -16,16** (2,59)

Note : (.) standard dev ; ***<1%, **<5%, *<10

Source: Authors

9. Conclusion

The objective of this work was to analyze the resilience strategies of family farms in rural areas and to assess the effect of these resilience strategies on farm productivity. To do this, we first identified relevant resilience strategies used by farms in rural Senegal in the 2018/2019 Annual Agricultural Survey. Then, we examined factors associated with the adoption of different resilience strategies using a multivariate Probit model. Finally, we assessed the impact of resilience strategies on the productivity of family farms.

We focus on three practices, the construction of dikes, crop rotation and the use of certified seeds as resilience strategies for farms in rural areas in the face of agricultural and climatic shocks. The multivariate analysis shows that the adoption of resilience strategies of family farms is strongly linked to climatic variables (humidity, temperature, precipitation), the level of education of the owner of the farm, the size of the agricultural household and the agroecological zone. The impact evaluation shows that these resilience strategies have a significantly positive impact on the productivity of family farms in rural areas.

The research results show that family farms in rural Senegal respond to agricultural hazards and climatic hazards by adopting strategies including construction of dikes, crop rotation and the use of certified seeds, in an effort to be resilient and prevent future hazards and to improve or maintain their agricultural yield.

The results of this study are largely consistent with those of many other studies in other countries (Di Falco et al., 2011; Diallo and Donkor, 2020; Khanal et al., 2018; Dessalegn et al., 2022). Ultimately, these results provide a basis for policies intended to facilitate the promotion of agriculture, for the design or redesign of agricultural programs and investments in the agricultural sector in rural Senegal. Findings are particularly important for the design of policies aimed at developing and promoting effective resilience strategies to deal with agricultural shocks, and hence offer guidance towards the achievement of SDG2: Zero Hunger.

While resilience strategies can be effective in supporting agricultural productivity, they can also be costly to implement. Public authorities through Extension and other support services can effectively play two roles: that of advising on the choice of appropriate strategies for each area and of trainer on the implementation of these different strategies. All of this is necessary to reduce maladaptation by farmers.

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References

1. Asfaw, S., Pallante, G., & Palma, A. (2018). Diversification strategies and adaptation deficit: Evidence from rural communities in Niger. *World Development, 101*, 219-234.
2. Call, M., & Sellers, S. (2019). How does gendered vulnerability shape the adoption and impact of sustainable livelihood interventions in an era of global climate change? *Environmental Research Letters*, *14*(8), 083005.
3. Makate, C., Makate, M., Mutenje, M., Mango, N., & Siziba, S. (2019). Synergic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in southern Africa. *Environmental Development*, *32*, 100458.
4. IPCC, (2021). Appendix. IPCC projections. In *Climate (*pp. 149-153). EDP Sciences.
5. Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2017). Social vulnerability indicators in disasters: Findings from a systematic review. *International Journal of Disaster Risk Reduction*, *22*, 219-227.
6. Aryal, A., Shrestha, U. B., Ji, W., Ale, S. B., Shrestha, S., Ingty, T., . . Raubenheimer, D. (2016). Predicting the distributions of predator (snow leopard) and prey (blue sheep) under climate change in the Himalayas. *Ecology and Evolution*, *6*(12), 4065-4075.
7. Devkota, R. P., Pandey, V. P., Bhattarai, U., Shrestha, H., Adhikari, S., & Dulal, K. N. (2017). Climate change and adaptation strategies in Budhi Gandaki River Basin, Nepal: a perception-based analysis. *Climatic Change, 140*(2), 195-208.
8. Niles, M. T., Brown, M., & Dynes, R. (2016). Farmer's intended and actual adoption of climate change mitigation and adaptation strategies. *Climatic Change, 135*(2), 277-295.
9. Zhang, H.-L., Zhao, X., Yin, X.-G., Liu, S.-L., Xue, J.-F., Wang, M., ... Chen, F. (2015). Challenges and adaptations of farming to climate change in the North China Plain. *Climatic Change, 129*(1-2), 213-224.
10. Banque Mondiale (2021): «Développement Local, Institutions et Changement Climatique au Sénégal, Analyse de la situation et recommandations opérationnelles », Département du développement social, Institutions sociales et changement climatique, Rapport, janvier 2021, p. 89.
11. Banque Mondiale (2006) : « Gestion des risques en milieu rural au Sénégal : revue multisectorielle des initiatives en matière de réduction de la vulnérabilité», Développement Humain II(AFTH2), Région Afrique, Rapport N°33435-SN, 30 mars 2006, p.163.
12. Lacroix, D., et al., (2021). *La moitié du niveau de la mer d'ici 2100, scénarios et conséquences*, Editions Quae.
13. Commission Économique pour l'Afrique (2017).Protocole de Maputo et les améliorations dans le secteur rural, No.ECA/18/006.
14. CIRAD-GRET (2021):«Analyser la diversité des exploitations agricoles. In : Memento de l'agronome », pp 321-344.
15. Faostat, F. (2017). Available online: http://www. fao. org/faostat/en/# data. *QC (accessed on January 2018)*.
16. République du Sénégal (2018) : « Rapport de l'Enquete Agricole Annuelle - Sénégal (EAA) 2018-2019», Rapport final, Septembre 2019, p.150.
17. Gregory, P. J., Ingram, J. S., & Brklacich, M. (2005). Climate change and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*(1463), 2139-2148.
18. Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.
19. IPCC, B. (2001). Climate Change: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, IPCC Working Group I Report.

20. Khanal, U., Wilson, C., Hoang, V.-N., & Lee, B. (2018). Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. *Ecological Economics, 144*, 139-147.
21. Khanal, U., Wilson, C., Lee, B. L., & Hoang, V.-N. (2018). Climate change adaptation strategies and food productivity in Nepal: a counterfactual analysis. *Climatic Change, 148*(4), 575-590.
22. Quan, S., Li, Y., Song, J., Zhang, T., & Wang, M. (2019). Adaptation to Climate Change and its Impacts on Wheat Yield: Perspective of Farmers in Henan of China. *Sustainability, 11*(7), 1928.
23. Diallo, A., Donkor, E., & Owusu, V. (2020). Climate change adaptation strategies, productivity and sustainable food security in southern Mali. Climatic Change, 1-19.
24. Onyeneke, R. U. (2020). Does climate change adaptation lead to increased productivity of rice production? Lessons from Ebonyi State, Nigeria. Renewable Agriculture and Food Systems, 1-15.
25. CISSE, A. B., & Khalifa, D. (2022). Perception du changement climatique et stratégies d'adaptation paysannes à Louga. *Espace Géographique et Société Marocaine*, *1*(60).
26. Basse, B. W., Mbaye, S., & Diop, O. (2022). Impact des bonnes pratiques agricoles sur le rendement des cultures d'anacarde (noix de cajou) au Sénégal.
27. Diallo, S., Faye, M., & Nacro, H. B. (2022). La variabilité pluviométrique et ses impacts sur les rendements et les surfaces cultivées dans le bassin arachidier de la région de Thiès (Sénégal). *VertigO-la revue électronique en sciences de l'environnement*.
28. Piya, L., Maharjan, K. L., & Joshi, N. P. (2013). Determinants of adaptation practices to climate change by Chepang households in the rural Mid-Hills of Nepal. *Regional environmental change*, *13*(2), 437-447.
29. Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental science & policy*, *12*(4), 413-426.
30. Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global environmental change*, *19*(2), 248-255.
31. Zheng, X., Su, L., Hu, S., Ye, Z., & He, J. (2015). Legendre wavelet for power amplifier linearization. *Analog Integrated Circuits and Signal Processing*, *84*(2), 283-292.
32. Biggs, E. M., Tompkins, E. L., Allen, J., Moon, C., & Allen, R. (2013). Agricultural adaptation to climate change: observations from the Mid-Hills of Nepal. *Climate and Development*, *5*(2), 165-173.
33. Yila, J. O., & Resurreccion, B. P. (2013). Determinants of smallholder farmers' adaptation strategies to climate change in the semi arid Nguru Local Government Area, Northeastern Nigeria. *Management of Environmental Quality: An International Journal*.
34. Lacy, S. M., Cleveland, D., & Soleri, D. (2006). Farmer choice of sorghum varieties in southern Mali: Managing Unpredictable Growing Environments and Resources. *Human Ecology*, *34*(3).
35. Fosu-Mensah, B. Y., Vlek, P. L., & MacCarthy, D. S. (2012). Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana. *Environment, Development and Sustainability*, *14*(4), 495-505.
36. Wang, J., Wang, E., Yang, X., Zhang, F., & Yin, H. (2012). Increased yield potential of wheat-maize cropping system in the North China Plain by climate change adaptation. *Climatic change*, *113*(3), 825-840.
37. Seo, S. N., & Mendelsohn, R. (2008b). Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management 1. *Agricultural Economics*, *38*(2), 151-165.

38. Tarfa, P., Ayuba, H., Onyeneke, R., Idris, N., Nwajiuba, C., & Igberi, C. (2019). Climate change perception and adaptation in Nigeria's Guinea Savanna: Empirical evidence from farmers in Nasarawa State, Nigeria. *Appl Ecol Environ Res, 17*(3), 7085-7112.
39. Soglo, Y. Y., & Nonvide, G. M. A. (2019). Climate change perceptions and responsive strategies in Benin: the case of maize farmers. *Climatic change, 155*(2), 245-256.
40. Waha, K., Müller, C., Bondeau, A., Dietrich, J. P., Kurukulasuriya, P., Heinke, J., & Lotze-Campen, H. (2013). Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change, 23*(1), 130-143.
41. Challinor, A. J., Watson, J., Lobell, D. B., Howden, S., Smith, D., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change, 4*(4), 287-291.
42. Huang, K.-T., & Hwang, R.-L. (2016). Future trends of residential building cooling energy and passive adaptation measures to counteract climate change: The case of Taiwan. *Applied Energy, 184*, 1230-1240.
43. Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics, 90*(1), 26-43.