



Climate change adaptation strategies, productivity and sustainable food security in southern Mali

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Abstract

Many people in African countries derive their livelihoods from agriculture. Therefore, unfavourable environmental and climatic conditions render them more vulnerable to increasing food insecurity and poverty rates. However, few studies have investigated how farmers' adaptation strategies affect farm productivity and household food security in the Sahelian region, notably Mali. We analyse factors that influence adaptation strategies to climate change and the impacts of the adaptation strategies on maize productivity and household food security in southern Mali. Farmers use adaptation strategies such as organic fertilizers, changing planting dates and growing of short duration maize varieties to mitigate against the negative effects of climate change. We find that farmer experience, number of livestock owned, off-farm employment, access to credit, farmer association and technical training exert positive effects on the use of planting short-duration maize varieties as an adaptation strategy, while distance to the farm shows a negative effect. We observe that household size, experience in maize farming, number of livestock owned and technical training positively influence farmers to change planting dates as an adaptation strategy. The use of organic fertilizers and short-duration maize varieties promote maize productivity and food security. We conclude that building farmers' adaptive capacity tends to reduce their vulnerability to climate change by increasing crop yields and food security.

Keywords Adaptation strategies · Climate change · Environmental change · Food security · Maize yield · Mali

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1 Introduction

Climate change is a great threat to the achievement of the Sustainability Development Goals (SDGs) of zero hunger and no poverty in sub-Saharan Africa, especially Mali (Krishnamurthy et al., 2012). Malnourishment, food insecurity and poverty are prevalent in Mali. Ten percent of children aged 6 to 59 months suffer from acute malnutrition, whereas 20% of the Malian population is food insecure (WFP 2019). Available statistics in 2012 further reveal that 66% and 51% of the rural and urban population are calorie deficient, respectively (Bocoum 2012). The annual loss of productivity due to malnutrition is estimated to be 145 million USD, which is equivalent to 4.06% of Mali's gross domestic product (WFP 2019). A major cause of this crisis is from adverse agro-climatic conditions in the country (Richardson et al. 2018; WFP 2019). Mali is located in the Sahelian zone, which is characterized by severe and frequent droughts, erratic rainfall and increasing environmental degradation (Funk et al. 2012; WFP 2019). The average rainfall between 2000 and 2009 was 12% lower than that of 1920 to 1969 (Funk et al. 2012). Since 1975, temperatures have increased by more than 0.8 °C across most parts of Mali, with typical rates of warming greater than 0.2 °C per decade (Funk et al. 2012). Funk et al. (2012) estimated that the 1975 to 2009 warming has been more than 0.7 °C during the June–September rainy season. The rising temperatures and declining rainfall patterns are detrimental to crop yields, especially maize, which requires more water. This leads to reduced food supply as well as overall availability of food (Krishnamurthy et al. 2012).

Many smallholder farmers in Mali are vulnerable to adverse effects of climate change due to their low adaptive capacity (Moseley 2011). In response to these climate change threats, smallholder farmers in Mali used agricultural adaptation strategies, which are not completely new but are evolving from traditional practices (Douxchamps et al. 2016). These adaptation strategies include the application of organic fertilizers, changing of planting dates and growing of short duration crop varieties. The application of organic fertilizers increases crop yields by improving soil moisture content and supply of nutrients to crops (Below et al. 2015; Douxchamps et al. 2016). Farmers change their planting dates in response to the rainfall pattern. Improved crop varieties, notably short duration varieties are drought tolerant, which produce better yields even during drying seasons (Lobell et al. 2008; Below et al. 2015).

In this study, we address the following research questions:

RQ1: What are the factors that influence the use of adaptation strategies to climate change by maize farmers in southern Mali?

RQ2: What are the impacts of the adaptation strategies on maize yield and food security of smallholder farm households?

In the present paper, we analyse the factors that influence maize farmers' adoption of climate change adaptation strategies and their impacts on maize productivity and household food security in southern Mali.

A study on the analysis of the success of different adaptation strategies in improving maize productivity and food security as well as the factors that influence the adoption of such strategies is timely and beneficial for a number of reasons. First, the agricultural sector contributes about 33% to the gross domestic product of Mali and employs 80% of the active labour force (Funk et al. 2012; USAID 2016). The agricultural sector is traditional small-scale and dependent on rainfall, which makes it highly vulnerable to erratic rainfall and rising temperatures. Second, the study specifically focuses on maize in the southern region of Mali

because it is one of the most important cereal crops in addition to sorghum, millet and rice produced by farmers and constitutes the main food source for farmers. Maize is also among the cereal crops targeted under a recent national agricultural policy, Agricultural Development Policy (PDA – Politique de Développement Agricole 2011–2020) to address food insecurity and poverty in Mali (FAO 2017). In Mali, the demand for maize for human consumption and livestock feed in the market has been rising. However, despite the increases in the production of maize, the country is still unable to meet the local demand (IFDC 2015). Moreover, the frequent occurrence of drought has rendered maize production more vulnerable to climate change than any other crop in the country, thereby worsening the food insecurity issue in the region (FAO 2017). It is therefore necessary that farmers' adaptive capacity is enhanced to minimize the negative effects of climate change on maize productivity to ensure a consistent food supply to meet the local demand. Given that agriculture is the main source of livelihood for most Malians, adaptive actions and policies promoting robust agricultural growth have become important drivers of economic growth, food security and poverty reduction.

The impacts of climate change on food production and food security in developing countries are well documented in the literature (Butt et al. 2005; Kurukulasuriya and Mendelsohn 2008; Krishnamurthy et al. 2012; Below et al. 2015; Douchamps et al. 2016; Nyuor et al. 2016; Giannini et al. 2017; Richardson et al. 2018). For instance, Butt et al. (2005) found out that climate change could lead to changes in crop yield from -17% to 6% in Mali whilst forage yield could decrease by $5\text{--}35\%$ and leading livestock animal weights to decrease by $14\text{--}16\%$. These indicate that climate change could, therefore, expose a higher proportion of the Malian population to hunger (Butt et al. 2005). However, the implementation of adaptation strategies, such as heat resistant cultivars, the adoption of existing improved cultivars, migration of cropping pattern, and expansion of crop, could effectively reduce climate change impacts, and lower the risk of hunger to as low as 28% . Evidence from Kurukulasuriya and Mendelsohn (2008) suggests a 51% rise in net revenue from crops in dryland if future warming is mild and wet in seven sub-Saharan African countries. On the contrary, a 43% decrease in crop revenue is projected, if future climates are hot and dry. Ebi et al. (2011) projected that the sensitivity of maize for changing weather conditions is relatively small—less than 10% under dry and wet scenarios in 2030 and 2060 in Mali. Adaptation strategies suggested by farmers and experts included crop diversification and germplasm improvement, soil and water management, access to equipment and fertilizers. The study by Nyuor et al. (2016) revealed that early season precipitation was beneficial for sorghum but harmful for maize production in Ghana. However, whilst mid-season precipitation promoted maize production, temperature levels for all seasons negatively affected net revenues for both crops except during the mid-season, where temperature exerted a positive effect on the net revenue of sorghum. In Mali, Giannini et al. (2017) observed that climate change lowered food security of subsistence farmers, whereas more food secure households showed a clear tendency towards livelihood diversification away from subsistence agriculture.

Some empirical studies have analysed the adaptation strategies used by farmers to mitigate adverse effects of changing climatic conditions as well as their impacts on food production (Di Falco et al. 2011; Webber et al. 2014; Below et al. 2015; Douchamps et al. 2016; Soglo and Nonvide 2019). Notably, Di Falco et al. (2011) found that access to credit, extension and information were the key drivers of farmers' climate change adaptation strategy in Ethiopia. Webber et al. (2014) observed that perception of climate change, labour availability, access to credit and farmer socioeconomic status constrained farmers to adapt to climate change. Douchamps et al. (2016) indicated that adaptation

strategies such as crop diversity, soil and water conservation, improved crop varieties and fertilizers improved the food security status of some households in West African countries, including Burkina Faso, Ghana and Senegal. Using a qualitative survey, Below et al. (2015) observed that lack of economic resources (capital, land, labour, tools), lack of cooperation and incompatibility between local farming systems such as cassava and grazing were the main barriers to adaptation actions in Tanzania. A recent survey by Soglo and Nonvide (2019) also showed that age exerted a negative effect, whereas gender, marital status, education, experience in maize production, access to credit, distance to market, ownership of television set and agricultural training showed positive effects on adaptation strategies used by maize farmers in Benin.

Sufficient empirical evidence exists on the nexus between climate change and food security. However, few studies have focused on the impacts of adaptation strategies on crop productivity and food security, especially in Mali, where climate change poses a great threat to the livelihoods of many vulnerable people (Douxchamps et al. 2016; Richardson et al. 2018). Notably, most of the existing studies employed less rigorous analytical methods such as generalized linear models and simulations in the empirical analyses. These models, however, are limited in accounting for self-selection bias into adoption of climate change adaptation strategies. Hence, the empirical estimates may not reflect the true picture of the impacts of the adaptation strategies on crop productivity and food security. The present study builds upon the existing studies (Douxchamps et al. 2016; Richardson et al. 2018) by applying a robust econometric approach, specifically, the propensity score matching to evaluate the impacts of adoption of the climate change adaptation strategies on crop yield and household food security in southern Mali. Limited empirical evidence also exists on the factors influencing the adoption of adaptation strategies as well as their impacts on crop yield and food security in Mali. The present study contributes to narrowing this knowledge gap by improving our understanding and throwing more light on what factors influence the adoption of climate change adaptation actions by maize farmers in southern Mali using a multinomial logit model. Findings from the present study are relevant for formulating climate-related policies to mitigate against climate change in Mali as well as other West African countries.

The rest of the paper is structured as follows. Section 2 discusses the analytical techniques used to address the main research questions. We present the key findings and their discussions in the third section. Section 4 outlines the key conclusions and policy implications based on the findings.

2 Materials and methods

2.1 Theoretical and empirical strategy

This study derives its theoretical foundation from the production theory, which establishes a physical relationship between agricultural output and a set of inputs using a given technology. In this study, we include adaptation strategies as farm inputs to mitigate the effects of climate change on land productivity. We express maize yield as a function of a set of farm inputs, including adaptation strategies as in (1):

$$Yield_i = \alpha + \gamma X_i + \varphi ADAPT_i \quad (1)$$

where $Yield_i$ denotes maize output per ha, X_i is a set of farm inputs, $ADAPT_i$ indicates a bundle of adaptation strategies adopted by farmers. α , γ and φ represent parameters to be estimated. We can estimate Eq. (1) using the ordinary least squares (OLS). However, the inclusion of the adaptation strategies would generate biased estimates if Eq. (1) is estimated with the OLS. The reason is that the adoption of adaptation strategies among farmers is not a random process but self-selection, thereby creating selection bias in the empirical analysis. Extant empirical studies have used some econometric approaches to address this selectivity bias issue (Owusu et al. 2011; Donkor et al. 2018; Donkor and Owusu 2019). The most common self-selection bias approaches are the instrumental variable approach, difference in difference and the propensity score matching (PSM) technique. The limitation with the instrumental variables approach is identifying appropriate instruments. The difference in difference method is applicable when the data is longitudinal. The PSM approach employed in the present study is able to control for observable characteristics but cannot account for unobservable factors (Owusu et al. 2011; Donkor et al. 2018; Donkor and Owusu 2019).

Farmers tend to use more than two adaptation strategies to mitigate against climate change effects. It is therefore important to explicate the factors that influence farmers' adoption of adaptation strategies. The adaptation strategies include organic fertilizers, changing planting dates and planting short duration crop varieties. We conceptualize the adoption process of adaptation strategies using the random utility theory. The random utility theory states that every individual is a rational decision-maker, maximizing utility relative to his or her choices. Based on this theory, we assume that given a set of adaptation strategies, farmers choose adaptation strategies that maximize their utility:

$$E[U(A_1)] > E[U(A_2)] \tag{2}$$

where $U(A_1)$ is the utility derived from adopting an adaptation strategy A_1 and $U(A_2)$ is the utility derived from an adopting adaptation strategy A_2 . The farmer i decides to adopt J adaptation strategy if the perceived utility from strategy J is greater than the benefit from adopting adaptation strategy, k , i.e.

$$U_{ij}(\varpi_j X_j + \varepsilon_j) > U_{ik}(\varpi_k X_k + \varepsilon_k), k \neq j \tag{3}$$

where U_{ij} and U_{ik} are the perceived utilities derived by farmer i from adaptation strategies j and k , respectively; X_i is a vector of explanatory variables that influence the choice of the adaptation strategy; ϖ_j and ϖ_k are parameters to be estimated; ε_j and ε_k are the error terms.

The economic problem discussed above concerns a decision to choose amongst different alternatives, and in the present study, we employ the multinomial logit (MNL) model. Specifically, we investigate the factors influencing the choice of the use of organic fertilizers, change of planting dates and planting of short duration crops as climate change adaptation strategies in maize production in southern Mali. The probability that a farmer i with X_i characteristics chooses an adaptation strategy j in the MNL framework can be specified as:

$$P_{ij} = \Pr(Y_i = 1) = \frac{e^{X_i' \varpi_j}}{1 + \sum_{j=1}^J e^{X_i' \varpi_j}}, \quad j = 1, \dots, J \tag{4}$$

where ϖ is a vector of parameters that satisfies $\ln(P_{ij}/P_{ik}) = X'(\varpi_j - \varpi_k)$. The multinomial logit (MNL) requires that the assumption of independence of irrelevant alternatives (IIA) is satisfied. Given that the estimated coefficients of the MNL are computed relative to the base variable, the direct interpretations of the signs and the magnitudes become difficult. We therefore compute the marginal effects of changes in the explanatory variables on the probability of choosing each of the climate change adaptation strategy (Wooldridge 2010). The marginal effects of the explanatory variables from the MNL model are computed as:

$$\frac{\partial P_{ij}}{\partial X_k} = \left(\varpi_{jk} - \sum_{j=1}^J P_j \varpi_{jk} \right) \tag{5}$$

Empirically, we express the adoption of the climate change adaptation strategies as a function of household characteristics, plot-level characteristics, institutional characteristics, perception variables and a location dummy using the MNL model:

$$\begin{aligned} ADAPT_{im} = & \varpi_{0m} + \sum_{k=1}^5 \varpi_{km} HHCHRCTS_{ikm} + \sum_{k=6}^8 \varpi_{km} PLOTLEVEL_{ikm} + \sum_{k=9}^{12} \varpi_{km} INSTITUTIONAL_{ikm} \\ & + \sum_{k=13}^{15} \varpi_{km} PERCEPTION_{ikm} + \varpi_{16m} LOCATION_{im} + \varepsilon_{im} \end{aligned} \tag{6}$$

where $ADAPT_{im}$ denotes m adaptation strategies (Organic fertilizers = 1, planting of short-duration maize varieties = 2, changing planting dates = 3).

$HHCHRCTS_{ikm}$ is a set of household characteristics such as the farmer’s age (years), education (number of years of formal education), household size (number of family members in the household), number of livestock owned, and experience in maize farming (years). $PLOTLEVEL_{ikm}$ represents a vector of plot-level characteristics, including distance from home to the farm in kilometres (km), plot ownership and plot size in hectares (ha). $IINSTITUTIONAL_{ikm}$ denotes a set of institutional characteristics, including frequency of extension contact, access to technical training, access to credit, participation in off-farm employment and membership of farmer association. $PERCEPTION_{ikm}$ denotes a set of perception variables, including short onset of rainy season, early onset of dry season and decrease in rain frequency. $LOCATION_{ikm}$ denotes a location dummy. ϖ_{0m} and ϖ_{km} are vectors of parameters to be estimated using the simulation maximum likelihood approach. ε_{im} represents the error term.

We expect household, farm, institutional and location-specific characteristics to influence the farmers’ use of adaptation strategies. The age of the farmer, number of years of schooling, household size, experience, land ownership, access to credit, frequency of extension contact and wealth of the farmer are expected to exert positive effects on the probability of adopting climate change adaptation strategies, whereas perceptions of farmers on the onset of late rainy season, early dry season and off-farm employments are expected to exhibit negative effects. We hypothesize that local climatic conditions and district level climate variables would have mixed effects on the adoption of climate change adaptation strategies. In the next section, we discuss the propensity score matching approach employed in the present study to estimate the

impacts of the climate change adaptation strategies on productivity and food security status of the sampled farming households in southern Mali.

2.2 Propensity score and treatment effects

We analysed the impacts of the climate change adaptation strategies on maize yield and household food security with the propensity score matching (PSM) approach (Sianesi 2004; Owusu et al. 2011; Donkor et al. 2018; Donkor and Owusu 2019). The propensity score $p(Z_i)$ is defined as the conditional probability of adoption of any of the three adaptation strategies considering the pre-adoption characteristics (Becker and Ichino 2002) as:

$$p(Z_i)\Pr(L_i = 1|Z_i) = E(L_i|Z_i)p(Z_i) = F\{h(Z_i)\} \tag{7}$$

where $L_i = (1, 0)$ is an indicator of adoption of an adaptation strategy, Z_i denotes a vector of pre-adoption characteristics and $F(\cdot)$ can be a normal or logistic cumulative distribution. The propensity score is predicted with either the logit or probit model (Sianesi 2004). The parameter of interest in PSM evaluation methodology is the average treatment effect on the treated (ATT). Given the propensity score, $p(Z_i)$, the ATT effect is evaluated as:

$$ATT = E[E(Y_i^1|L_i = 1p(Z_i))]E[E(Y_i^0|L_i = 1p(Z_i))|L_i = 1] \tag{8}$$

where Y_i^1 and Y_i^0 are the two counterfactual outcomes of adoption and non-adoption of climate change adaptation strategy. In the present study, we employed matching algorithms such as the nearest neighbour, kernel-based and radius matching.

2.3 Measurements of outcome indicators

Constant changes in climatic conditions negatively affect the maize production, food systems and food security of smallholder farmers. Therefore, climate change adaptation strategies are expected to increase maize yield and reduce food insecurity levels of households in rural areas. As noted by Di Falco et al. (2011), the higher the probability of adoption of climate change adaptation strategies, the more likely household-level food insecurity would decrease. As already indicated, we use maize yield and household food insecurity as the outcome indicators in the present paper. We measure maize yield as the grains weight (kilograms) per harvested area (hectare). Various household food insecurity indicators exist in the empirical literature. In the present study, we use the Household Food Insecurity Access Scale (HFIAS) to measure the food insecurity status of the maize farm households. The HFIAS comprises a series of questions for the food insecurity (access), which allows predictable responses to be gathered through inquiry as outlined on the food insecurity scale (Leroy et al. 2015). The Household Food Insecurity Access Scale score for each household is computed by adding the coded frequency of experience for all the questions as:

$$HFIAS(0-27) = (Q_{1a} + Q_{2a} + Q_{4a} + Q_{5a} + Q_{6a} + Q_{7a} + Q_{8a} + Q_{9a}) \tag{9}$$

where a denotes the coded frequency of experience and Q represents the various questions we asked the farmers regarding their household food insecurity. Generally, the higher the score,

the higher the food insecurity status of the household. Households with *HFIAS* score between 0 and 4 are classified as food secure and those with *HFIAS* score above 4 are classified as food insecure.

2.4 Source of data and data description

The present study was conducted in two districts—Koutiala and Bougouni—in the Sikasso region of southern Mali. Maize is produced in all the districts in the Sikasso region of Mali (Fofana et al. 2011). As shown by Fig. 1, Koutiala and Bougouni rank second and third in terms of maize production in the region, and they contribute about 14% (56,714 t) and 12% (47,653 t), respectively, to the total maize output. This shows that the two districts are among the most important maize producing areas in the Sikasso region. Koutiala covers an area of about 18,000 km² with a population of 575,253 inhabitants. It is located in the Sudano-Sahelian zone between 12° 38' N and 5° 66' W with a wet season of around 3–4 months, and a dry season for the rest of the months. The average annual rainfall is around 895 mm, with a maximum temperature of about 38 °C. The size of Bougouni is about 20,028 km², with a population of 459,509 inhabitants. This district is situated between 11° 24' N and 7° 35' W in the Sudano-Guinea zone. The duration of the rainy season is about 4–5 months with the rest being mostly dry. The maximum temperature is around 33 °C, and the average rainfall is of about 1100 mm.

The study employed primary data collected using a multi-stage sampling approach. First, the two districts were purposively selected due to high maize production and about 20% and 40% frequency of occurrence of drought risk in the districts (Fofana et al. 2011). Second, three out of the six agricultural subsections from Koutiala District and four out of the eight in

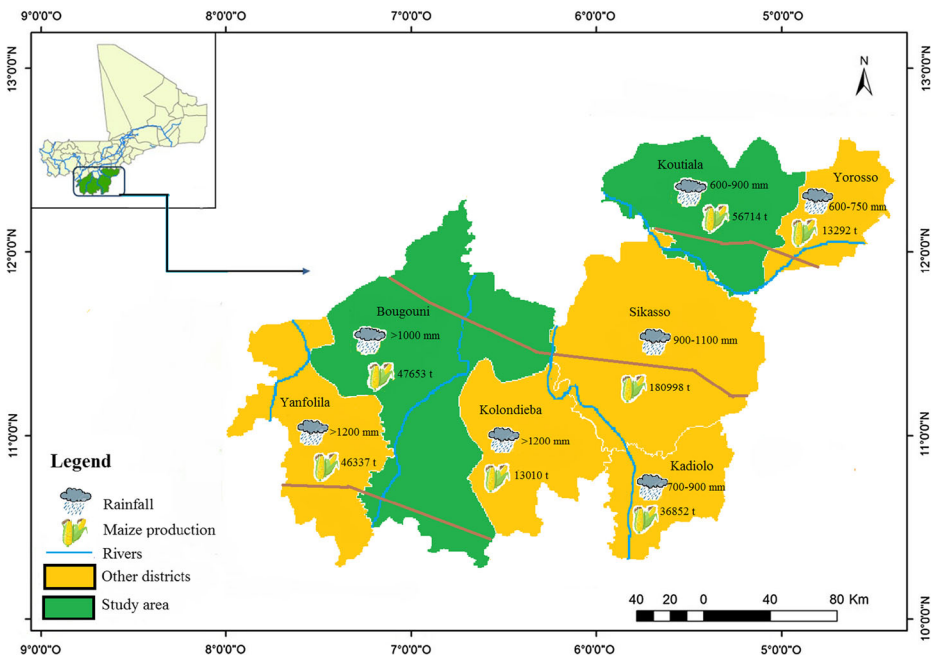


Fig. 1 Map of the study area. Source: Institut Geographie du Mali, 2019

Bougouni District were purposively selected. The agricultural subsections represent about 50% of the total agricultural subsection in each district. Third, two communities were randomly selected from each of the agricultural subsection, making a total of 14 randomly selected communities for the study (i.e. six from Koutiala and eight from Bougouni). During the final stage, 155 maize farmers from Koutiala and 153 from Bougouni were randomly sampled, making a total sample size of 308 farm households for the study (see Table 1). The sample size for the study was determined using the formula, $n = \frac{N}{1+Ne^2}$ proposed by Yamane (1967), where n denotes the required sample size, N denotes the total population and e represents the margin of error. Using the level of confidence of 92% and a margin of error of 8% (0.08), we obtained a sample size of 308 for the survey. The margin of error of 8% enabled us to obtain a representative sample. It also assisted us to avoid large sample size, which would have led to inefficient data collection due to inadequate financial resources and time constraints.

With the aid of structured questionnaires, we collected data on personal, household, farm and institutional characteristics, climate change adaptation strategies and perceptions of maize farmers on the adaptation strategies and food security status of the farm households using the Household Food Insecurity Access Scale (HFIAS).

3 Results and discussions

3.1 Summary statistics of the characteristics of maize farmers

Over two thirds of the maize farmers adopt one or more forms of adaptation strategies, with a greater proportion of food secure households engaged in such actions (Table 2). The dominant forms of adaptation strategies the farmers used to mitigate against climate change in southern Mali included the use of organic fertilizers, change of planting dates and planting of short duration crop varieties. In line with our finding, Challinor et al. (2018) also found short duration and drought or pest tolerant crop varieties as the most commonly adopted climate

Table 1 Sampled communities

Region	District	Agricultural subsection	Community	Sample size	
Sikasso	Koutiala	Koutiala	Sincina	22	
			N'Goutjina	13	
		Molobala	Molobala	31	
			N'tesso	20	
		N'Pessoba	N'Pessoba	42	
			Fakolo	26	
		Total	155		
	Bougouni	Bougouni	Bougouni	Diambala	17
				Sido	44
		Faraguaran	Faraguaran	Kouroulamini	13
		Dogo	Dogo	Dogo	20
				Tegela	7
		Garalo	Garalo	Bladje	19
					13
		Total	153		
Total sample size		308			

Source: Authors' computation

change adaptation strategies in Mali. We find a significant positive association between household food security status and adoption of planting of short duration crops. There is also evidence to suggest that the majority of the maize farmers who used planting of short duration crops as a climate change adaptation strategy are more food secure. However, the associations between food security status of the maize farmers and the use of organic fertilizers and change of planting dates as adaptation strategies are not statistically significant even at the 10% level (Table 2). Generally, we find that most of the maize farmers (51.8%) are food insecure. Such farm households find it difficult to manage food demand and consumption throughout the year. Wiggins and Keats (2013) reported that about 67% of the world's most food insecure are smallholder farm households in developing countries.

The descriptive results show significant differences in maize yields for farmers who are food secure and those who are food insecure (Table 3). Therefore, maize yield is crucial to household food security in Mali. We also find significant differences between farm households who are food secure and those who are not food secure concerning the adoption of planting of short duration crops as an adaptation strategy. This descriptive result is expected looking at the annual prolonged extreme temperature conditions in southern Mali. The results further indicate statistical differences between food secure and food insecure farm households in the sampled districts of Koutiala and Bougouni in terms of the number of years of schooling of the household head, distance of maize plots from home and the plot size. Given the statistical differences, we find these variables very crucial to the adoption of climate change adaptation strategies, which also have the tendency to affect maize yields and household level food security.

3.2 Factors influencing adoption of climate change adaptation strategies

The Wald chi-square value of 128.97 from the diagnostic test is statistically significant at the 1% level, indicating that the explanatory variables jointly influence the farmers' decision to adopt the adaptation strategies (Table 4). The results from variance inflation factor (VIF) testing for the presence of multicollinearity in the models indicate that multicollinearity is not a problem in the models since the mean VIF of 1.48 is far less than the threshold of 10 (Table 4).

3.2.1 Household characteristics

The variable, *Household size*, exerts positive significant effects on the use of organic fertilizers and changing planting dates as adaptation strategies, *albeit* at the 10% level. The results thus indicate that an increase in the farmers' household size tends to increase the likelihood of using

Table 2 Climate change adaptation strategies and food security status

Adaptation strategies	Category	Food secure (<i>N</i> = 148)	Food insecure (<i>N</i> = 160)	Pearson chi-square
Planting short duration crops	Yes (73.1)	121 (82%)	100 (63%)	14.067***
	No (26.9)	27 (18%)	60 (37%)	
Use of organic fertilizers	Yes (74%)	115 (78%)	113 (71%)	2.0031
	No (26%)	33 (22%)	47 (29%)	
Change of planting dates	Yes (71.8%)	108 (73%)	117 (73%)	0.001
	No (28.2%)	40 (27%)	43 (27%)	

Source: Authors' computation

Table 3 Data and description of variables

Variable name	Description	Food secure	Food insecure	Difference in means
Outcome variable				
Maize yield	Grains weight (kg) per harvested area (ha)	1906.44 (67.63)	1558.44 (61.81)	347.10***
Treatment variables				
Use of organic fertilizers	Dummy = 1 if farmer adopts organic fertilizers as an adaptation strategy and 0 otherwise	0.78 (0.034)	0.71 (0.036)	0.071
Change of planting dates	Dummy = 1 if farmer change the planting dates as an adaptation strategy and 0 otherwise	0.730 (0.04)	0.731 (0.04)	-0.001
Planting short duration crops	Dummy = 1 if farmer plants short duration crops as an adaptation strategy and 0 otherwise	0.82 (0.03)	0.63 (0.04)	0.192***
Household characteristics				
Male headed	Dummy = 1 if household head is a male and 0 otherwise	0.98 (0.14)	0.94 (0.24)	0.04*
Age	Age of household head in years	48.15 (11.64)	49.36 (11.59)	-1.21
Education	Number of years of schooling of the farmer	4.32 (3.83)	2.89 (3.33)	1.42***
Household size	Number of family members in the household	21.92 (11.88)	24.29 (14.97)	-2.37
Number of livestock owned	Number of livestock owned	37 (31)	31 (21)	6*
Maize farming experience	Experience in maize farming	17.28 (8.89)	16.48 (9.36)	0.77
Plot-level characteristics				
Distance from home to the farm	Distance from home to maize farm in km	3.63 (2.58)	3.01 (2.84)	0.61**
Plot size	Maize farm land holding in ha	3.38 (3.24)	2.44 (2.77)	0.94***
Plot ownership	Dummy = 1 if farmer owns the land and 0 otherwise	0.99 (0.12)	0.969 (0.18)	0.02
Institutional characteristics				
Frequency of extension visits	Number of visits by extension officer in the season	4.79 (3.16)	5.18 (3.38)	-1.056
Access to credit	Dummy = 1 if farmer has access to credit and 0 otherwise	0.82 (0.39)	0.78 (0.42)	0.04
Off-farm employment	Dummy = 1 if farmer participates in any off-farm employment and 0 otherwise	0.64 (0.48)	0.63 (0.49)	0.01
Membership of FBO	Dummy = 1 if farmer is member of any farm-based-organization and 0 otherwise	0.89 (0.31)	0.84 (0.36)	0.048
Technical assistance	Dummy = 1 if farmer receives technical training and 0 otherwise	0.872 (0.336)	0.800 (0.401)	0.072*
Perception variables				
Short onset of rainy season	Dummy = 1 if farmer reported short onset of rainy season and 0 otherwise	0.82 (0.39)	0.84 (0.37)	-0.02
Early onset of dry season	Dummy = 1 if farmer reported early onset of dry season and 0 otherwise	0.97 (0.16)	0.99 (0.11)	-0.02
Decrease in rain frequency	Dummy = 1 if farmers has experienced decrease in frequency of rain and 0 otherwise	0.77 (0.42)	0.80 (0.40)	-0.03
Location dummy				
Koutiala	Dummy = 1 if farmer lives in Koutiala and 0 otherwise	0.40 (0.49)	0.60 (0.49)	-0.20

*, ** and *** indicate statistical significance of 10%, 5% and 1% levels, respectively. Figures provided in table are means and those in the parentheses are standard deviations. Source: Authors' computation

Table 4 Multinomial Logit estimates of maize farmers' choices of adaptation strategies

Variable	Use of organic fertilizers	Planting short duration crops	Change of planting dates
	Marginal effects	Marginal effects	Marginal effects
<i>Household characteristics</i>			
Age	-0.001 (0.001)	-0.001 (0.002)	0.002 (0.002)
Education	-0.008 (0.013)	0.019 (0.022)	-0.011 (0.024)
Household size	0.049* (.027)	-0.040 (0.043)	0.089* (0.048)
Maize farming experience	0.010 (0.026)	0.162*** (0.042)	0.153*** (0.046)
Number of livestock owned	0.044* (0.022)	0.069* (0.037)	0.112*** (0.041)
<i>Plot-level characteristics</i>			
Distance from home to farm	-0.013*** (0.004)	-0.019* (0.011)	0.006 (0.011)
Plot size	0.037 (0.023)	0.005 (0.038)	0.042 (0.042)
Plot ownership	0.120** (0.047)	-0.199 (0.151)	0.079 (0.164)
<i>Institutional characteristics</i>			
Technical training	-0.021 (0.029)	0.107** (0.053)	0.128** (0.057)
Access to credit	0.051* (0.030)	0.111** (0.051)	0.162*** (0.055)
Off-farm employment	0.105*** (0.031)	0.187*** (0.049)	0.081 (0.057)
Membership of FBO	0.062* (0.034)	0.026 (0.075)	0.037 (.079)
<i>Perception variables</i>			
Short onset rain season	-0.110 (0.076)	-0.149 (0.147)	0.261 (0.183)
Decrease in number days of rain	-0.627 (3.105)	0.157 (9.116)	0.471 (3.989)
Early onset of dry season	-0.223 (2.578)	0.887 (6.059)	0.664 (3.482)
<i>Location dummy</i>			
Koutiala	-0.029 (0.033)	0.047 (0.054)	-0.018 (0.060)
<i>Diagnostic statistics</i>			
Test of joint effects (Wald chi-square)	128.97***		
Multicollinearity (mean VIF)	1.48	1.48	1.48
Pseudo R-square	0.298		
Pseudo log likelihood	-151.778		
Observation	308		

*, ** and *** indicate statistical significance levels of 10%, 5% and 1%, respectively. Robust standard errors are in parentheses. Source: Authors' computation

organic fertilizers and changing planting dates as adaptation strategies amongst the maize farmers by 0.050 and 0.089, respectively (Table 4). Generally, large farming households tend to have a higher demand for food. The farmers, therefore, use organic fertilizers and change planting dates to respond to climate change to be able to increase food supply and meet such demand.

Experience does not exert significant effect on the use of organic fertilizers but shows significant positive effects on the adoption of short-duration crop varieties and changing planting dates at the 1% level (Table 4). Specifically, increasing the farmer's experience in maize farming by a year leads to a 0.153 increase in the likelihood of changing planting dates and a 0.162 increase in the likelihood of planting short duration maize varieties as adaptation strategies. Experienced maize farmers accumulate enough knowledge on climatic conditions over time and can easily detect irregularities in the rainfall pattern as well as rising temperatures. These experienced farmers respond to the unpredictable climatic patterns by adjusting the planting dates accordingly and planting short-duration maize varieties.

Our empirical result shows significant positive effects of the number of livestock owned by farmers on the use of organic fertilizers and change of planting dates as adaptation strategies. As the number of livestock increases by a unit, the probability of adopting organic fertilizers as

an adaptation strategy by the maize farmers increases by 0.044. Farmers who own livestock use the livestock faecal matter as an organic manure on their maize farms. The result further shows a 0.122 increase in the likelihood of the farmer to change planting dates as an adaptation strategy when livestock ownership increases by a unit. Farmers with enough livestock such as donkey and oxen could easily change their planting dates by using the animals for land preparation when planting. Our finding is consistent with that of Ebi et al. (2011), who argued that farmers with more livestock have the capacity to purchase agricultural inputs, as income from livestock sales could be invested in crop production. The farmer's age and education, however, do not show significant effects on the use of climate change adaptation strategies (Table 4).

3.2.2 Plot-level characteristics

We find negative significant effects of *Distance to farm* on the probability of adopting organic fertilizers and short-duration maize varieties as adaptation strategies at the 1% level and 10% level, respectively (Table 4). As the distance from home to the farm increases by a kilometre, farmers are less likely to adopt organic fertilizers and short-duration maize varieties by 0.013 and 0.019, respectively. These results are consistent with the study by Soglo and Nonvide (2019). Organic fertilizers such as animal manure are heavy, so transporting them over a long distance tends to be expensive. High transportation costs tend to increase the overall cost of production, which may discourage farmers whose farms are located far from their homestead to use organic fertilizers. Ebi et al. (2011) and Solgo and Nonvide (2019), providing similar empirical evidence, argued that when smallholder farms are located far away from home, farmers tend to pay less attention to such farms.

Plot ownership shows a significant positive effect on organic fertilizers at the 5% level, but it has no significant effects on the use of planting of short-duration maize varieties and changing planting dates as adaptation strategies. Ownership of farm plots increases the likelihood of farmers to use organic fertilizers as an adaptation strategy by 0.120. The application of organic fertilizers has a long-term effect on soil fertility. The land tenure security associated with having owned farmland assists farmers to reap the benefits of long term investments on the land. Although *plot size* exerts positive effects on the adoption of adaptation strategies, the marginal effects are not statistically significant. This shows that plot size does not affect farmers' climate change adaptation decisions in the present study.

3.2.3 Institutional characteristics

The marginal effects of *Technical training* on the use of short-duration maize varieties and changing planting dates are significantly positive (Table 4). Farmers who benefit from technical training are more exposed to relevant knowledge on adaptation actions that require innovations. They are therefore more likely to adapt to climate change by planting short-duration maize varieties and changing planting dates.

We find that farmers' participation in off-farm employment tends to positively influence the adoption of organic fertilizers and short-duration maize varieties (Table 4). When farmers participate in off-farm employments, they generate extra incomes, which reduce the liquidity constraints in the purchase of organic fertilizers and short-duration maize varieties.

The marginal effect of the variable, *Membership of farmer association* is positive for adoption of organic fertilizers at the 10% significance level (Table 4). This result demonstrates

that farmers who belong to a farmer association tend to have a higher probability of adopting organic fertilizers than non-members. Being a member of a farmer association in Mali is an important social capital, where farmers share knowledge on agricultural innovations and acquire skills on how to respond to unfavourable climatic conditions. In addition, farmer associations are important platforms through which agricultural extension agents and non-governmental organizations disseminate information on adaptation strategies to farmers.

The marginal effects of the access to credit variable are positive and significant for the adoption of organic fertilizers, short-duration maize varieties and changing planting dates (Table 4). Farmers with access to credit are more likely to adopt the adaptation strategies compared to those who face credit constraints. Adopting organic fertilizers and short-duration maize varieties are capital-intensive agricultural adaptation actions, which require access to credit, especially for poor farmers, to be financially empowered to purchase organic fertilizers and short-duration maize varieties. Our findings support previous studies which also argued that access to credit is crucial for adoption of appropriate adaptation strategies by farmers in Africa (Di Falco et al. 2011; Webber et al. 2014; Below et al. 2015; Soglo and Nonvide 2019).

3.2.4 Perception variables

The empirical results indicate no significant effects of the perception variables on the use of climate change adaptation strategies analysed in the present study. This evidence suggests that farmers' perceptions on climate change do not statistically influence their adoption of adaptation strategies in the sampled districts in Mali.

3.2.5 Location-specific variable

Our results indicate no significant effects of the location-specific variables on adoption of climate change adaptation strategies. This suggests that in the present paper, the location of the farmer does not affect climate change adaptation decisions.

3.3 Impacts of climate change adaptation strategies

The propensity scores used in the estimation of the average treatment effects on the treated (ATT) presented in Table 5 were predicted with a probit model. Since the propensity scores serve as a device to balance the observed distribution of covariates across the treated and the untreated groups, we do not undertake a detailed interpretation of the propensity score estimates in the present study (Owusu et al. 2011). However, we observe that the distribution of the propensity scores before and after matching appears to balance the treated and untreated groups extremely well (Fig. 2) and shows substantial bias reduction (Fig. 3), thereby underscoring the relevance of the propensity score matching approach employed in the present paper.

The average treatment effects on the treated (ATT) were estimated using the nearest neighbour (NNM), kernel-based (KBM) and radius (RM) matching algorithms. We find that only the ATT estimate (150.34 kg/ha) from RM is statistically significant at the 1% level in the case of maize yield (Table 5). This result shows that farmers who use organic fertilizers as an adaptation strategy are able to generate 150.34 kg/ha of maize output higher than those who do not. In the case of food insecurity, we observe that ATT (-1.23) from the KBM is statistically significant at the 5% level (Table 5). Our empirical findings suggest that using organic

Table 5 Average treatment effect on the treated (ATT)

Adaptation strategies	Outcomes	Matching methods	ATT	Standard errors
Use of organic fertilizers	Maize yield (kg/ha)	NNM	292.58	335.18
		KBM	116.85	204.92
		RM	150.34***	55.12
	Food insecurity	NNM	-0.86	1.09
		KBM	-1.23**	0.68
		RM	-0.20	0.18
Planting of short duration crops	Maize yield (kg/ha)	NNM	336.99***	133.68
		KBM	275.85**	127.75
		RM	243.10***	56.99
	Food insecurity	NNM	-1.01	0.68
		KBM	-0.87*	0.53
		RM	-0.93***	0.18
Change of planting dates	Maize yield (kg/ha)	NNM	140.85	201.61
		KBM	69.98	159.53
		RM	63.73	55.49
	Food insecurity	NNM	-0.54	0.56
		KBM	-0.43	0.49
		RM	-0.31	0.33

*, ** and *** indicate statistical significance of 10%, 5% and 10% levels. NNM denotes nearest neighbour matching, KBM denotes kernel-based matching and RM denotes radius matching. Source: Authors' computations

fertilizers as an adaptation to climate change tends to promote maize yield and reduce food insecurity in southern Mali. The application of organic fertilizers increases the organic matter content in the soil, promotes microbial activities and conserves soil moisture. Enhanced microbial activities help to improve soil aeration and structure. Moreover, organic fertilizers supply macronutrients to the crops. These desirable soil properties are necessary for soil fertility improvement, which could enhance maize yield in the era of climate change and variability in Mali. Higher maize yields may be translated into higher incomes and improved livelihoods. Some portions of the stock of harvested maize may also be consumed to improve the nutritional and food security status of the farming households.

The ATT estimates from NNM, KBM and RM are 336.99 kg/ha, 275.85 kg/ha and 243.10 kg/ha, respectively (Table 5). These estimates are statistically significant at the 5% level. What these empirical results suggest is that farmers who plant short-duration maize varieties obtain yields of 243.10 kg/ha to 336.99 kg/ha greater than those who do not plant

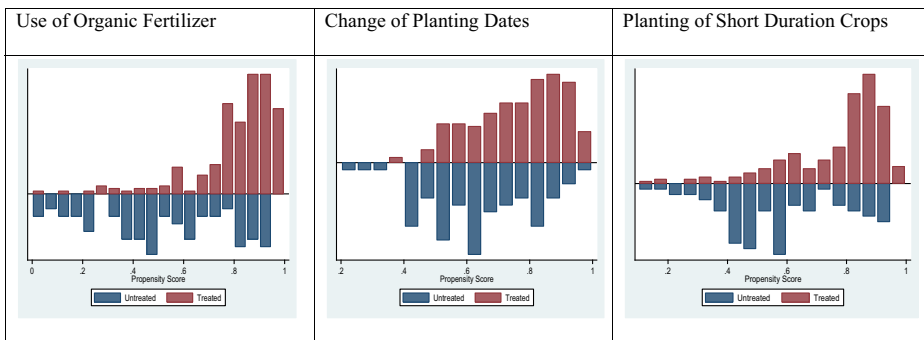


Fig. 2 Distribution of propensity scores for treated and untreated samples

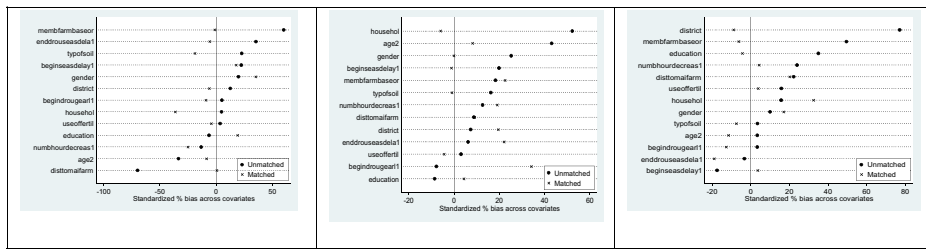


Fig. 3 Distribution of standardized % bias across matched and unmatched samples

short-duration maize varieties as an adaptation strategy. The ATT estimates from the KBM (-0.87) and from the RM (-0.93) are statistically significant at the 10% and 5% levels, respectively (Table 5), implying that planting of short-duration maize varieties reduces food insecurity. As indicated by the sampled farmers, the length of the raining season in Mali has reduced over the past 10 years. Hence, the need to grow maize varieties that could mature within a short period of time. Besides the short maturity period, the varieties are also high yielding which enhances the maize yield of farmers who grow such varieties.

We also observe that ATT estimates of changing planting dates on maize yields and food insecurity are not statistically significant even at the 10% level. These results show that changing planting dates may not necessarily translate into increased yields and food insecurity declines in maize producing households in southern Mali.

4 Conclusions and policy implications

The present study employed cross-sectional data from two districts in southern Mali to analyse the factors that influence the adoption of climate change adaptation strategies by maize farming households and the impacts of the adoption of the adaptation strategies on maize yield and household food insecurity. The multinomial logit model (MNL) and the propensity score matching (PSM) techniques were employed in the empirical analyses. The empirical results from the MNL indicate that long distance from home to the farm discourages maize farmers from using organic fertilizers as an adaptation strategy, whereas household size, number of livestock owned, access to credit, participation in off-farm employment and membership of a farmer association increase the likelihood of farmers to adapt to climate change using organic fertilizers. Our results further show that farmer's experience in maize farming, credit access, number of livestock owned, participation in off-employment and technical training exert positive effects on the use of planting of short-duration maize varieties as an adaptation strategy. However, farmers whose farms are far away from home are less likely to grow short-duration maize varieties as a climate change adaptation strategy. We also find that household size, experience in maize farming, number of livestock owned, access to credit and technical training positively influence farmers to change their planting dates to suit the rainy seasons.

After controlling for a wide range of observable factors, including household characteristics, plot-level characteristics, institutional characteristics, perception on climate related variables and location dummy, the findings from the PSM suggest that using organic fertilizers and planting short-duration maize varieties as adaptation strategies exert positive effects on maize yield and negative effects on food insecurity. We recommend that maize farmers use organic

fertilizers and short-duration maize varieties to reduce vulnerability to climate change, promote maize yields, improve food security status, strengthen the rural economy and enhance the welfare of rural farmers in southern Mali.

Our study has contributed to the general literature on economics of climate change adaptation strategies by expanding on the existing studies (Di Falco et al. 2011; Webber et al. 2014; Below et al. 2015; Douxchamps et al. 2016; Soglo and Nonvide 2019). With the rigorous quantitative analyses, the study has improved our understanding on how farmers respond to climate change and the extent to which their adaptation strategies have affected their farm productivity and food security. The findings from the study are relevant for food security agencies in prioritizing adaptation actions for the most food insecure households in Mali. The adaptation strategies, particularly organic fertilizers and planting of short-duration varieties are capital intensive, suggesting that wealthy farmers (those with more livestock, access to credit and who participate in off-employment) are more empowered to use them in their maize production. We therefore recommend that policy makers and relevant stakeholders should prioritize adaptation actions for the most food insecure households by easing their liquidity constraints with affordable credit schemes. Agrifood policy in Mali should also promote the formation of farmer associations and strengthen the existing ones. As a national policy, the meteorological services in Mali should be strengthened so that they can educate and provide real-time weather information to improve the understanding of smallholder farmers on the change in climatic conditions. This will in turn accelerate the promotion of the use of organic fertilizers and planting of short duration crops as relevant climate change adaptation strategies to increase maize production and household food security in southern Mali.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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