Climate change and adoption of sustainable land management practices in the Niger basin of Benin

Article *in* Natural Resources Forum · February 2018

DOI: 10.1111/1477-8947.12142

2 authors:

Boris Odilon Kounagbe Lokonon
West African Science Service Center on Climate Change and Adapted Land Use (W…

Ahmadou aly Mbaye
Cheikh Anta Diop University, Dakar

Natural Resources Forum 42 (2018) 42–53 DOI: 10.1111/1477-8947.12142

Climate change and adoption of sustainable land management practices in the Niger basin of Benin

Boris O. K. Lokonon and Aly A. Mbaye

Abstract

Due to the important role that the agricultural sector plays in sustaining growth and reducing poverty in developing countries, the adoption of practices that have the potential to simultaneously improve agricultural productivity while minimizing environmental impacts is essential. This paper examines the determinants of farmers' perceptions of climate change and subsequent adoption of sustainable land management practices in the Niger basin of Benin. Binary and multivariate probit models are applied in a two-stage regression procedure to cross-sectional data collected through a survey of 545 randomly selected farm households in 28 villages. The findings indicate that there are substitutabilities among three pairs of sustainable land management practices being used by the farmers. Climate change perception is positively related to land tenure, experience in farming, number of relatives, tractor use, and membership in farmers' organizations, and negatively related to household size, remoteness, and plough use. Moreover, the findings reveal that the uptake of land management practices is related to assets, land tenure, education level of the household head, remoteness, social network, non-irrigated land size, having a farm located near a river/lake/stream, tractor and plough use, being a subsistence farmer or not, and memberships in farmers' organizations. The adoption of sustainable land management practices could be encouraged through improving access to markets, adequate roads, and technologies, as well as by promoting membership in farmers' organizations.

Keywords: Adaptation strategies; climate change; Heckman two-step; multivariate probit; perception; sustainable land management practices.

1. Introduction

Climate change constitutes a serious challenge for the world, especially in developing countries (Di Falco and Veronesi, 2013; IPCC, 2013). It hampers and will continue to affect agricultural production in many parts of the world, particularly in developing countries, due to their low adaptive capacities. Nevertheless, some parts of the world may benefit from changes in climate, including areas located in developing countries. But the overall impact of climate change is negative (IPCC, 2014). The main factors that are responsible for changes in climate are anthropogenic greenhouse gases (GHGs). While agricultural activities release GHGs in the atmosphere, agriculture is not the economic sector that generates the highest GHG emissions (IPCC, 2013). That said, agriculture contributes to just under a quarter of anthropogenic GHG emissions (IPCC, 2014). It should be noted that agriculture is the main source of livelihood for the West African rural population, and is mostly rain-fed (Callo-Concha *et al*., 2013), and therefore is affected and will continue to be affected by climate change, *ceteris paribus*, with differentiable impacts across geographic units. Through a literature review of 16 studies, Roudier *et al*. (2011) showed that the impacts of climate change on crop yields are larger in the northern part of West Africa (−18% median impact) than in the southern part (−13%).

The agricultural sector in Benin is important for sustaining growth and reducing poverty. It is the main contributor to employment and to the gross domestic product (GDP). It has contributed to 35% of GDP, and up to 70% in employment generation (République du Bénin, 2014). Moreover, agricultural exports occupy a preeminent place in Benin's external trade. Therefore, well-developed agriculture is important in achieving pro-poor economic growth, tackling food insecurity, and meeting the sustainable development goals (SGDs). It has been admitted that people who are currently vulnerable to the effects of weather events and climate fluctuations and shocks are expected to become even more vulnerable in the future if

Boris Odilon Kounagbè Lokonon is at the Université de Parakou, Parakou, Benin. E-mail: odilonboris@gmail.com
Aly Ahmadou Mbaye is at the Université Cheikh Anta Diop, Dakar, Senegal. E-mail: mbayealy93@yahoo.fr

they do not adopt appropriate adaptation strategies (Lokonon, 2015).

Therefore, farmers must adopt strategies to mitigate the adverse impacts of climate change on their activities so as to further avoid declining agricultural productivity. Thus, the transformation of the agricultural sector is critical in addressing climate change. The transformation of agriculture can pass, among others, through improved agricultural productivity and the simultaneous minimalization of environmental impacts as advocated by the ongoing debate on sustainability issues. The main adaptation strategies identified in the literature include crop diversification, changing planting dates, planting trees, planting quick-maturing crop varieties, using pesticides or fungicides, irrigation, mixed crop-livestock farming systems, income diversification (development of off-farm activities), and soil and water conservation techniques (Okonya *et al*., 2013; Nhemachena *et al*., 2014).

However, many of the adaptation strategies lead to environmental degradation (Tilman *et al*., 2002; Branca *et al*., 2013). Therefore, greater attention is being given to alternative models of intensification through sustainable land management practices (Branca *et al*., 2013). Sustainable land management practices have the potential to generate private benefits for farmers by improving soil fertility and structure, conserving soil and water, enhancing the activity and diversity of soil fauna, and strengthening the mechanisms of element cycling (Caviglia and Kahn, 2001; Lee, 2005; Louhichi *et al*., 2010; Branca *et al*., 2013). Moreover, such practices can generate significant public environmental goods, such as climate change mitigation, by reducing GHG emissions and increasing the removal of these gases through carbon sequestration (FAO, 2009, 2010; Branca *et al*., 2013). Antle and Diagana (2003) argued that sustainable agricultural development is of paramount importance in combating poverty and environmental degradation.

Due to the urgency of adaptation, most of the recent literature has focused on adaptation strategies. The recent papers focused on the determinants of either perception of climate change or adaption strategies (e.g., Haden *et al*., 2012; Moyo *et al*., 2012; Wiid and Ziervogel, 2012; Maponya and Mpandeli, 2013; Yegbemey *et al*., 2013; Nhemachena *et al*., 2014; Tanellari *et al*., 2014), or have linked farmers' adaptation strategies to climate change perception (e.g., Maddison, 2007; Gbetibouo, 2009; Okonya *et al*., 2013; Kansiime *et al*., 2014). The difference between these two categories of papers is that the first category ignores the two-stage process of the adoption of adaptation strategies. Indeed, the adaptation process involves perception and adaptation decision stages. There is also a body of literature on the adoption of sustainable land management practices (e.g., Ajayi, 2007; Asafu-Adjaye, 2008; Kassie *et al*., 2009; Willy and Holm-Müller, 2013; Kulindwa, 2016). Moreover, Branca *et al*. (2013) provided an important literature review on food security, climate change, and sustainable land management.

The recent literature shows that most of the time, farmers are aware of climate change, even though their awareness is not always consistent with historical climate records. Many factors such as gender, education level, access to extension services, and social networks are found to play an important role in the adaptation process. From the perspective of the microeconomics of technology adoption, schooling, one's own learning and social learning, credit constraints, risk, and incomplete insurance are among the factors that influence decisions pertaining to technology adoption (Foster and Rosenzweig, 2010). The rapid diffusion of technology may be constrained by many factors such as lack of credit, inadequate farm size, and unstable supply of complementary inputs (Feder *et al*., 1985; Lin, 1991; Lee, 2005). Yet the findings of the recent literature are relatively location-specific and vary substantially across adaptation strategies, and it is difficult to find such studies in the context of Benin. Moreover, as it is of paramount importance to give up the previous model of intensification, there is a need to undertake research on the adoption of sustainable land management practices to shed light on the factors that can favour their adoption in specific geographical and socio-economic contexts. Note that Yegbemey *et al*. (2013) analysed farmers' decisions to adapt to climate change under various property rights in Northern Benin, but focused on maize producers and did not account for the two-stage process of adaptation. The study by Yegbemey *et al*. (2013) is solely about adaptation strategies, and this is what makes it different from this paper, which is specific to sustainable land management practices. Nevertheless, Yegbemey *et al*. (2014) accounted for the two-stage process of adaptation, but focused on adaptation strategies, which are aggregated into a single binary variable. Furthermore, Oyerinde *et al*. (2015) analysed hydro-climatic changes in the Niger basin and the consistency of local perceptions, and identified adaptation strategies adopted by farmers. Their identification of adaptation strategies was done through descriptive statistics, and any further analysis has not been carried out.

This research aims to contribute to filling the literature gap by analysing the determinants of farmers' perceptions and farm-level adoption of sustainable land management practices in the context of the Niger basin of Benin. Therefore, the specific objectives are: (i) to analyse farmers' perceptions of climate change; (ii) to analyse sustainable land management practices adopted by farmers to mitigate the impacts of climate change in regard to their perceptions; and (iii) to investigate substitutability and complementarity among the various sustainable land management practices adopted by farmers. Based on the findings, policy implications are drawn to strengthen farmers' awareness of climate change and improve the adoption of appropriate strategies that will enable increased agricultural productivity and contribute to mitigating GHGs.

The remainder of this research is structured as follows. The next section describes the methods used. Then, the results and discussion are presented in Section 3. Finally, Section 4 concludes the paper with policy implications.

2. Methods

2.1. Model

Adaptation to climate change is a two-stage process, and accounts for both perception and adaptation. The first stage of the process accounts for whether the farmer perceives climate change as a real threat, and the second stage of the process accounts for the farmer's choice of adaptation strategy depending on his/her perception of climate change. The choice of adaptation strategy is a sub-sample of the perception stage, and there is a possibility that this sub-sample is non-random, and differs from the sample of those who do not perceive climate change as a real threat, and may be source of sample selection bias. Heckman (1976, 1979) developed a framework to analyse this kind of process. The Heckman framework considers the selection bias as an omitted variable problem. Multinomial discrete choice models can be also used to model adaptation decisions. However, the shortcomings of these methods are the difficulty in the interpretation of the influence of the explanatory variables on the choices of each of the m original separate adaptation measures (Nhemachena *et al.*, 2014). Although the usual multivariate probit model overcomes the shortcomings of the multinomial models, it does not account for the selection bias. Thus, a variant of the Heckman two-step procedure (Heckman, 1976, 1979) must be used to account for this two-stage process due to its advantages over multinomial and multivariate probit models, as these models are not suitable for analysing the two-step procedure of adaptation described.

The two-stage process of perception and adaptation is described by the following equations:

$$y_i = x_i'\beta + \varepsilon_i, \tag{1}$$

$$z_i^* = w_i'\gamma + \mu_i, \tag{2}$$

$$z_i = \begin{cases} 1 & if\ z_i^* \geq 0 \\ 0 & otherwise \end{cases}. \tag{3}$$

Equation (1) is the second stage of adaptation, the outcome model. In Equation (1), y_i stands for the choice of sustainable land management practice, conditional on climate change perception, x_i represents the vector of explanatory variables, β refers to the vector of parameters to be estimated, and ε_i is the error term. Equation (2) represents the first stage of the Heckman sample selection model, and constitutes the selection model. The vectors of regressors of Equation (2) are described by w_i, whereas γ and μ_i represent the parameters to be estimated and the error term, respectively. z_i^* is a latent variable related to the perception of climate change. The selection variable z_i^* is not observed. Rather, we observe only its sign. Hence, we can infer the sign of z_i^*, but not its magnitude (Greene, 2012). We typically observe only whether a farmer perceives climate change as a real threat or not. The selection equation in the Heckman framework is a binary probit model. In this framework, y_i is observed only when $z_i = 1$. After estimating this model, the inverse Mills ratio must be generated and used among regressors of the outcome model to correct the selection bias. If the coefficient associated with the inverse Mills ratio is not significantly different from zero, there is no evidence of a sample selection problem.

In the context of this research and in order to overcome the limitations of the univariate and multinomial discrete choice models, the outcome equation is a multivariate probit model. The multivariate probit model helps to account for the heterogeneities in the determinants of the adoption of the different practices as well as for the relationships between them; either they are complementary or competing (Kassie *et al.*, 2009). The multivariate probit model is characterized by a set of m binary dependent variables y_{ij} such that[1]:

$$y_{ij} = \begin{cases} 1\ if\ x_i'\beta_j + \varepsilon_{ij} > 0 \\ 0\ \ if\ x_i'\beta_j + \varepsilon_{ij} \leq 0, j = 1, 2, \ldots, m, \end{cases} \tag{4}$$

where y_{ij} represents the choice of sustainable land management practices j by the farmer i, x_i is a vector of explanatory variables, β_1, β_2, …, β_m are conformable parameter vectors, and the random error terms ε_{i1}, ε_{i2}, …, ε_{im} are distributed as multivariate normal (MVN) distribution with zero means, unitary variance and $m \times m$ contemporaneous correlations matrix $R = [\rho_{jk}]$, with density $\varphi(\varepsilon_{i1}, \varepsilon_{i2}, \ldots, \varepsilon_{im}; R)$:

$$(\varepsilon_{i1}, \varepsilon_{i2}, \ldots, \varepsilon_{im})' \sim MVN \left[0, \begin{pmatrix} 1 & \rho_{12} & \cdots \rho_{1m} \\ \rho_{12} & 1 & \cdots \rho_{2m} \\ \vdots & \vdots & \ddots \vdots \\ \rho_{1m} & \rho_{2m} & \cdots 1 \end{pmatrix} \right]. \tag{5}$$

It is worth mentioning again that in this modelling framework, the inverse Mills ratio generated from the selection equation needs to be added as an explanatory variable in the outcome equations to account for the selection bias.

2.2. Data and variables

The research was conducted in the Niger basin of Benin located at 11°N–12°30′N and 2°E–3°20′40E and covering

[1] Refer to Nhemachena *et al.* (2014) and Cappellari and Jenkins (2003) for full details on the multivariate probit models.

Table 1. Number of households surveyed

AEZs	Communes	Villages	Number of agricultural households surveyed per village
		Garou 1	20
AEZ I	Malanville	Bodjecali	20
		Kassa	20
		Toumboutou	20
		Bouhanrou	20
	Banikoara	Tintinmou Bariba	20
		Tintinmou Peulh	20
		Sirikou	20
AEZ II		Donwari	20
	Kandi	Sonsoro Bariba	20
		Kandifo Peulh	20
		Tankongou	20
		Angaradebou	15
		Tepa	16
	Nikki	Kali	20
		Serekale Centre	24
		Kassakpere	20
		Kossou	20
	Bembereke	Bembereke Ouest	20
AEZ III		Kpebera	20
		Kabanou	20
		Makrou-Gourou	20
	Kouande	Beket Peulh	20
		Gantieco	20
		Chabi Couma	15
		Moupemou	20
AEZ IV	Natitingou	Kota Monongou	20
		Perma	15

43,313 km^2. The Niger basin of Benin belongs to the watershed of the Middle Niger, and both wholly and partially covers five out of the eight agro-ecological zones (AEZs) in Benin. It belongs to the Soudan savannah zone and has one rainy season, which lasts from May to November. Farmers in the basin use mostly family labour, and rely relatively less on improved inputs, production methods and farm equipment. There is the coexistence of both customary and modern land ownership systems in the country.

The primary data used in this research were collected through a household survey conducted among 545 farm households in the Niger basin of Benin in April–May 2013. A three-stage sampling procedure was used to sample households: random selection of seven communes within the AEZs, random selection of 28 villages within selected communes, and random selection of farm households within selected villages (Table 1). It is the part of the dataset that includes farmers' perceptions of climate change and the adaptation strategies adopted by farmers that are used in this research. The survey was conducted to analyse and assess vulnerability and resilience to climate shocks, and to carry out adaptation policy simulations.[2] Among the adaptation strategies adopted by farmers, those deemed as sustainable land management practices are used in this paper.

The dependent variables for the outcome equation are five binary variables characterizing the adoption of the sustainable land management practices of planting trees, building stone bunds, using less chemical fertilizer application, rotating crops, and intercropping with nitrogen-fixing crops such as beans, groundnuts, and soybeans. The dependent variable for the selection equation is whether the farmer perceives climate change as a real threat. This variable takes the value 1 if the farmer perceives at least a change in rainfall patterns or in temperatures, and 0 otherwise. Table 2 presents descriptive statistics of perception and the identified main sustainable land management practices.

In light of the literature on the adoption of sustainable agricultural practices, the independent variables included in the estimations (e.g., Lee and Stewart, 1983; D'Souza *et al*., 1993; Caviglia and Kahn, 2001; Lee, 2005; Kassie *et al*., 2009; Willy and Holm-Müller, 2013; Kulindwa, 2016) are: the education level of the household head, the size of the household, the gender of the household head, livestock assets, access to credit, non-irrigated farm size, distance to the nearest market, experience in farming, access to extension services, social network (number of close friends and relatives within the village), assets

[2] Further details on the survey are available in Lokonon (2015).

Table 2. Farmers' perceptions and main farm-level sustainable land management practices

Variables	Percent
Perceive at least a change in temperatures or in rainfall patterns	85.14
Planting trees	57.80
Stone bunds	8.07
Less chemical fertilizer application	21.47
Crop rotations with nitrogen-fixing crops	31.56
Intercropping with nitrogen-fixing crops	09.72

excluding land and livestock, access to electricity, land tenure, distance from dwelling to paved or tarred roads, having the major part of the farm near a river/lake/stream, tractor use, plough use, being a subsistence farm household or not, membership in labour sharing groups, and membership in farmers' organizations.

Education level is found to play an important role in the perception of climate change (Fosu-Mensah *et al*., 2012; Silvestri *et al*., 2012) and in adopting sustainable agricultural practices (D'Souza *et al*., 1993). Household size can influence the likelihood of perceiving climate change as a real threat (Silvestri *et al*., 2012) and the subsequent adoption of adaptation measures (Kassie *et al*., 2009). For instance, large households are endowed with labour, which can be used to accomplish labour-intensive activities. Climate change perception may vary with respect to the gender of the household head (Maddison, 2007; Fosu-Mensah *et al*., 2012). Likewise, the adoption of sustainable land management practices is also hypothesized to be affected by the gender of the household head (Kassie *et al*., 2009). Assets and wealth can also be correlated with the perception of climate change (Deressa *et al*., 2011; Fosu-Mensah *et al*., 2012; Silvestri *et al*., 2012). Thus, assets are captured in this paper by livestock assets, non-irrigated farm size, and other assets, excluding land and livestock. In the same vein, tractor and plough use are included in the two equations to capture their influence on climate change perception and on the uptake of sustainable agricultural practices. Lee and Stewart (1983) and Kassie *et al*. (2009) arrived at the conclusion that livestock assets and farm size favour the uptake of sustainable agricultural practices. However, Willy and Holm-Müller (2013) found that farm size negatively influences soil conservation efforts. For farmers with financial constraints, credit is important to invest in adaptation strategies (Willy and Holm-Müller, 2013). For Fosu-Mensah *et al*. (2012), access to credit enables farmers to adapt to climate change, and so renders them to perceive a trend in rainfall patterns and in temperatures.

Proximity to markets positively affects the likelihood of perceiving climate change as a real threat, and of subsequent adaptation (Maddison, 2007). We also control for the distance from the dwelling to paved or tarred roads, since farmers in remote areas hardly have access to the main markets of their regions. Thus, the likelihood to adopt sustainable land management practices is hypothesized to decrease with the distance from the dwelling to paved or tarred roads. Likewise, we also expect that the odds to perceive climate change as a real threat decrease with this distance. Through experience, farmers become concerned about sustainable land use (Caviglia and Kahn, 2001). Therefore, we expect the uptake of sustainable land management practices to increase with years of experience in farming. Farmers' abilities to perceive a change in the climate are also positively related to experience in farming (Maddison, 2007; Silvestri *et al*., 2012). Improved information facilitates the uptake of sustainable land management practices (Lee, 2005). Access to improved information can be through extension services, farmers' organizations, and labour sharing groups. Our expectation is that access to extension services, membership in farmers' organizations and membership in labour sharing groups will be positively associated with the adoption of sustainable agricultural practices. These factors can also enable farmers to detect changes in climate (Maddison, 2007; Deressa *et al*., 2011; Fosu-Mensah *et al*., 2012; Silvestri *et al*., 2012). Lasco *et al*. (2016) found that the perception of changes in rainfall is significantly associated with access to electricity, suggesting the inclusion of this variable among the regressors of climate change perception in this study. Access to electricity facilitates access to information from media. Access to electricity is also found to play an important role in perceiving the importance of trees in coping with climate change (Lasco *et al*., 2016). Thus, we expect that adopting sustainable land management practices will be positively associated with access to electricity.

Social capital facilitates soil conservation efforts (Willy and Holm-Müller, 2013). Social capital is captured in this paper through both the number of close friends and relatives within the village. We expect a positive influence of social capital on the adoption of sustainable agricultural practices. Social capital is also important for climate change perception (Deressa *et al*., 2011; Okonya *et al*., 2013). Indeed, farmers may have access to information that enables them to perceive climate change from the vantage point of their social networks. Land tenure is essential to perceiving changes in climate (Fosu-Mensah *et al*., 2012), supporting its inclusion in the selection equation. It is recognized that land tenure security fosters investments in sustainable agricultural practices (Kassie *et al*., 2009; Willy and Holm-Müller, 2013). We thus account for land tenure in the outcome model. Farmers who have their farms close to rivers can easily use water for irrigation purposes (Willy and Holm-Müller, 2013). Therefore, we hypothesize that having the major part of the farm near a river/lake/stream facilitates the adoption of sustainable land management practices and enables farmers to detect changes in rainfall patterns. For Maddison (2007: 25), "subsistence farmers are far more likely to notice climate than other kinds of farmers". We expect that this finding will hold in the context of the Niger basin of Benin. Furthermore, we expect that subsistence farmers may be different from other types of farmers in terms of practising sustainable agriculture. A detailed description of the independent variables, their descriptive statistics, and their expected signs on climate change perception and the adoption of sustainable land management practices are presented in Table 3.

3. Results and discussion

The findings suggest that 85.14% of the farmers perceived climate change (at least a change in rainfall patterns or in temperature) as a real threat. Among the strategies adopted by farmers to mitigate the adverse impacts of climate change on their activities, five consisted of sustainable land management practices. Sustainable agricultural practices encompass many types of practices (Table 4), and these practices fall under several categories, such as agronomy, organic fertilization, minimum soil disturbance, water management, and agroforestry. Among these sustainable land management practices, planting trees was the most adopted by farmers (57.80% adoption rate). About one-third (31.56%) of the farm households relied on crop rotations with nitrogen-fixing crops. As for less chemical fertilizer application, the findings reveal that about one-fifth (21.47%) of the farm households have adopted it. The adoption rate of the remaining two identified sustainable land management practices is less than 10%; they amount to 8.07% and 9.72% for stone bunds and intercropping with nitrogen-fixing crops, respectively. Therefore, farmers in the Niger basin of Benin have adopted agricultural practices that are sustainable in response to changes in weather and climate conditions. It should be noted that these strategies have been available to farmers for a long time; however, not all farmers were implementing them, and they may have begun practising them to mitigate the adverse impacts of climate change on their activities. So, these practices may not be considered as innovations. That said, they still may not have existed in all localities for as long.

The estimation results of the probit regression model used to explain the odds that farm households perceive climate change as a real threat are presented in Table 5. Overall, the model is statistically significant. The findings show that the perception of climate change is positively related to land tenure, experience in farming, number of relatives, tractor use and membership in farmers' organizations, and negatively related to household size, distance from dwelling to the nearest market, as well as plough use. Farm households with family land are more likely to perceive climate change as a real threat compared to those with either rented, leased or community land. Thus, secure land tenure appears to play an important role in the perception of climate change (Maddison, 2007; Fosu-Mensah *et al*., 2012). The likelihood of perceiving climate change as a real threat increases with years of experience in farming. Similar results have been found by Gbetibouo (2009) and Silvestri *et al*. (2012). This finding suggests that experience with farming activities is of paramount importance in acquiring knowledge about climate change. Thus, the more the farmer is experienced, the more she/he is likely to perceive climate change as a real threat. Likewise, the odds of perceiving climate change as a real threat increase with the number of relatives the household has within the village. This result is in line with what Deressa *et al*. (2011) found. Therefore, social networks are important in raising farmers' awareness of climate change. Indeed, farmers can access weather and climate information through their social networks.

Farm households that are members of farmers' organizations are more likely than their counterparts that are not members of farmers' organizations to perceive climate change as a real threat. This finding suggests that farmers' organizations constitute a channel through which farmers have access to information on weather and climate conditions. The findings also indicate that climate change perception is, to some extent, associated with tractor use. Farm households that use tractors are more likely to perceive climate change as a real threat compared to those that do not. Tractor use is related to wealth and market production. Thus, as they are profit-oriented economic agents, farmers who use tractors account for climate change when making decisions. The probability of perceiving climate change as a real threat is found to decrease with household size, suggesting that farm-household members may have different perceptions of climate change, leading to household confusion regarding climate trends. The result is contradictory to that of Silvestri *et al*. (2012), who found that household size is positively associated with climate change perception, although the influence is not significant. Likewise, the likelihood of perceiving climate change as a real threat decreases with the distance from the dwelling to the nearest market. Farmers may obtain climate information at marketplaces and when those places are far from their dwellings, they cannot easily access them. Farm households that use ploughs are found to be less likely than their counterparts that do not use ploughs to perceive climate change as a real threat. This finding is in contradiction with our expectation. Like tractor use, plough use would have a comparable influence on the likelihood to perceive changes in climate. This may be because plough use does not require as much financial means as tractor use. In the Niger basin of Benin, farmers may use either their own draft animals or may borrow them from their neighbours.

The results of the estimation of the determinants of the adoption of sustainable land management practices are presented in Table 6. The results of the correlation coefficients of the errors terms are significant for three pairs of equations, indicating that they are correlated (planting trees and less chemical fertilizer application, planting trees and crop

Table 3. Explanatory variables and expected signs

Variables	Description	Mean	Standard deviation	Minimum	Maximum	Expected signs* Model 1	Expected signs* Model 2
Livestock asset value	In local currency (CFA F)†	1,149,589	4,726,039	0	9.91e+07	+/−	+/−
Asset value excluding land and livestock	In local currency (CFA F)	309,505	440,833	0	4,770,000	+/−	+/−
Access to electricity	Dummy variable (1 if yes and 0 if no)	0.22	0.42	0	1	+	+
Land tenure							
Rented, leased or community land	Dummy variable (1 if yes and 0 if no)	0.04	0.20	0	1	−	+/−
Own land	Dummy variable (1 if yes and 0 if no)	0.69	0.46	0	1	+	+
Family land	Dummy variable (1 if yes and 0 if no)	0.27	0.44	0	1	+	+
Household size	In number of persons	7.94	4.55	1	32	+/−	+/−
Gender of household head	Dummy variable (1 if male and 0 if female)	0.97	0.18	0	1	+/−	+/−
Education level of household head	In years of formal education	1.69	3.18	0	15	+	+
Experience in farming	In years	22.71	15.02	2	80	+	+
Distance from dwelling to nearest market	In km	2.27	3.67	0.01	25	−	−
Distance from dwelling to paved or tarred roads	In km	11.06	18.42	0	150	+/−	−
Number of relatives	In number of persons	8.85	13.33	0	120	+/−	+
Number of close friends	In number of persons	2.74	2.83	0	30	+/−	+
Non-irrigated farm size	In ha	6.85	5.85	0	45	+/−	+/−
Major part of the farm located near a river/lake/stream	Dummy variable (1 if yes and 0 if no)	0.41	0.49	0	1	+/−	+
Tractor use	Dummy variable (1 if yes and 0 if no)	0.12	0.32	0	1	+	+
Plough use	Dummy variable (1 if yes and 0 if no)	0.55	0.50	0	1	+	+
Subsistence	Dummy variable (1 if the farm household does not sell a part of its production and 0 if no)	0.92	0.27	0	1	+/−	+
Access to extension services	Dummy variable (1 if yes and 0 if no)	0.38	0.48	0	1	+	+
Access to credit	Dummy variable (1 if yes and 0 if no)	0.16	0.36	0	1	+	+
Membership in labour sharing groups	Dummy variable (1 if yes and 0 if no)	0.24	0.43	0	1	+/−	+
Membership in farmers' organizations	Dummy variable (1 if yes and 0 if no)	0.36	0.48	0	1	+/−	+

Notes: *Model 1 and model 2 refer to the outcome and the selection models, respectively. †In 2013, $1 = CFA F 494.04.

rotations with nitrogen-fixing crops, planting trees and intercropping with nitrogen-fixing crops). These findings indicate that these land management practices are substituted (negative correlation), supporting the assumption of interdependence between them, which may be due to the substitutability of the different practices, and also from omitted household-specific factors (unobservable or immeasurable factors) that affect their uptake, such as managerial ability (Kassie *et al*., 2009) and indigenous knowledge (Nhemachena *et al*., 2014). These findings are in line with those of Kassie *et al*. (2009), who found interdependence (positive correlation) between conservation tillage and compost, conservation tillage and chemical fertilizer, and compost and chemical fertilizer in a semi-arid region of Ethiopia. There are substantial differences (heterogeneities) in the estimated coefficients across equations, supporting the appropriateness of differentiating between sustainable land management practices. Moreover, a likelihood ratio test, based on the log-likelihood values of the multivariate and univariate models, indicates significant

Table 4. Sustainable land management practices

Sustainable land management practices	Details of the practices
Agronomy	Cover crops
	Crop rotation and intercropping with nitrogen fixing crops
	Improved fallow rotations
Organic fertilization	Compost
	Animal and green manure
Minimum soil disturbance	Minimum tillage
	Mulching
Water management	Terraces, contour farming
	Water harvesting and conservation
Agroforestry	Trees on cropland (contours, intercropping)
	Bush and tree fallows
	Live barriers/buffer strips with woody species

Source: Branca *et al*. (2013).

joint correlations $\mathcal{X}^2(10) = 18.86$; $probability > \mathcal{X}^2 = 0.04$, justifying the estimation of the multivariate probit that considers different sustainable land management practices as opposed to separate univariate probit models, and consequently the unsuitability of aggregating them into one sustainable land management practice. The coefficients associated to the inverse Mills ratio are significant in two equations, justifying its inclusion. Thus, the non-inclusion of the inverse Mills ratio will lead to biased results attributed to sample selection bias.

Livestock asset ownership increases the likelihood of the uptake of stone bunds. For instance, farmers with high livestock assets are mixed crop-livestock farmers, and therefore they are better able to cope with changes in climate patterns compared to specialized crop or livestock farmers (Nhemachena *et al*., 2014). The more assets farm-households have, the more likely they are to take up tree planting. Indeed, farmers with more financial resources at their disposal can change their management practices to respond to climate change (Nhemachena *et al*., 2014). Farmers with their own land are more likely to adopt intercropping with nitrogen-fixing crops compared to those with either rented, leased or community land. Private property increases the probability of the adoption of adaptation strategies (Nhemachena *et al*., 2014). Likewise, farm-households with family land are more likely to practice intercropping with nitrogen-fixing crops, and less likely to apply chemical fertilizer. Yegbemey *et al*. (2013) found that inheriting land increases the probability of adopting

Table 5. Estimation results of the perception equation

Variables	Coefficients ts	P-values	Marginal effects
Livestock asset value	3.27e−08	0.331	4.38e−09
Asset value excluding land and livestock	3.55e−07	0.299	4.75e−08
Access to electricity	−0.232	0.191	−0.034
Land tenure (Rented, leased or community land taken as reference)			
Own land	0.355	0.264	0.053
Family land	1.106***	0.004	0.107
Household size	−0.035*	0.067	−0.005
Gender of household head	−0.132	0.762	−0.016
Education level of household head in years	0.019	0.482	0.003
Experience in farming	0.022***	0.002	0.003
Distance from dwelling to nearest market	−0.038**	0.046	−0.005
Distance from dwelling to paved or tarred roads	−0.002	0.654	−2.31e−04
Number of relatives	0.048*	0.056	0.006
Number of close friends	0.049	0.316	0.007
Non-irrigated farm size	−0.021	0.174	−0.003
Major part of the farm located near a river/lake/stream	0.131	0.443	0.017
Tractor use	1.236**	0.013	0.086
Plough use	−0.534***	0.003	−0.070
Subsistence	0.295	0.260	0.047
Access to extension services	0.003	0.987	3.64e−04
Access to credit	−0.322	0.107	−0.051
Membership in labour sharing groups	−0.038	0.833	−0.005
Membership in farmers' organizations	0.393**	0.031	0.049
Constant	0.160	0.764	
Observations		545	
Log pseudolikelihood		−173.866	
Wald $\mathcal{X}^2(23)$		63.31	
$Prob > \mathcal{X}^2$		0.000	

Note: ***, **, * significant at 1%, 5% and 10%, respectively.

Table 6. Estimation results of the multivariate probit model

Variables	Plant trees	Stone bunds	Less chemical fertilizer application	Rotations	Intercropping
Livestock asset value	7.19e–08	2.80e–08**	−4.98e–09	3.29e–08	1.40e–08
Asset value excluding land and livestock	7.57e–07***	1.61e–08	−6.98e–08	9.95e–08	−2.22e–07
Land tenure (Rented, leased or community land taken as reference)					
Own land	0.444	−0.376	−0.066	0.179	4.509***
Family land	−0.304	−0.163	0.965**	0.209	4.537***
Household size	0.003	0.037	0.023	−0.025	0.001
Gender of household head	0.297	−0.250	0.032	−0.209	0.430
Education level of household head in years	−0.039	−0.049	−2.5e–04	0.051**	0.051**
Experience in farming	−0.002	0.001	0.007	0.006	0.004
Distance from dwelling to nearest market	−0.040**	−0.055*	0.037*	−0.002	−0.007
Distance from dwelling to paved or tarred roads	−0.010**	−0.010**	0.003	−0.020***	0.012**
Number of relatives	0.015**	0.005	−0.013	−0.017**	0.001
Number of close friends	−0.043	−0.171***	−0.011	−0.019	−0.044
Non-irrigated land size	−0.020	−0.051**	−0.009	0.045***	0.022
Major part of the farm located near a river/lake/stream	−0.400**	0.052	0.179	−0.258*	0.212
Tractor use	0.448	1.061***	0.984***	0.611**	−0.575*
Plough use	−0.059	−0.095	0.252	−0.137	−0.365*
Subsistence	0.080	0.620	1.121***	0.924***	0.377
Access to extension services	−0.053	−0.261	0.042	−0.188	−0.322
Access to credit	−0.121	−0.240	−0.144	−0.040	−0.120
Membership in labour sharing groups	0.218	−0.054	−0.270	0.181	−0.007
Memberships in farmers' organizations	−0.092	0.447*	0.110	−0.008	−0.398*
Inverse Mills ratio	−0.255	1.736***	1.656**	0.732	−0.009
Constant	0.508	−1.546**	−2.899***	−1.138	−6.299***
	Rho1	Rho2	Rho3	Rho4	Rho5
Rho2	−0.080				
Rho3	−0.191*	−0.089			
Rho4	−0.218**	−0.138	−0.049		
Rho5	−0.247**	−0.021	−0.031	0.094	
Observations = 416 Log pseudolikelihood = −887.295	Wald $\mathcal{X}^2(110) = 2540.23$	*Prob* $> \mathcal{X}^2 = 0.000$			

Notes: Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: $\mathcal{X}^2(10) = 18.8595$; *probability* $> \mathcal{X}^2 = 0.0421$. *, **, *** Significant at 10%, 5%, and 1%, respectively.

adaptation strategies. These findings suggest that secure land tenure is positively associated with the likelihood to take up sustainable land management practices. Therefore, it is of paramount importance to secure land ownership through enforcing laws, strengthening the decision of adopting adaptation strategies to improve agricultural productivity, and contributing to mitigating GHG emissions.

The odds of the uptake of crop rotations and intercropping with nitrogen-fixing crops increase with the formal education level of the household heads. These findings are in line with D'Souza *et al*. (1993), who found that education is positively associated with the adoption of sustainable agricultural practices. However, Yegbemey *et al*. (2013) found mixed impacts (negative and positive) of household head education level on the adoption of adaptation practices among maize producers in northern Benin. The likelihood to apply less chemical fertilizer increases with the distance to the nearest market. Nevertheless, the decisions to plant trees and to adopt stone bunds are negatively associated with the distance to the nearest market. This is relatively consistent with the findings of Nhemachena *et al*. (2014). The probability of planting trees, and of building stone bunds and crop rotations with nitrogen-fixing crops, decreases with the distance to paved or tarred roads. Certainly, remote farmers lack access to relevant information on sustainable land management practices. Conversely, the likelihood of taking up intercropping with nitrogen-fixing crops increases with the distance to paved or tarred roads. The probability of taking up crop rotations with nitrogen-fixing crops decreases with the number of relatives, suggesting that strong social networks are detrimental to the uptake of this practice. Likewise, the decision to practice stone bunds is negatively associated with the number of close friends. But, the odds of planting trees increase with the number of relatives. Indeed, Willy and Holm-Müller (2013) found that social capital facilitates participation in collective action initiatives, which then is beneficial for individual soil conservation efforts.

The likelihood of taking up crop rotations with nitrogen-fixing crops increases with non-irrigated land size. However, the odds of adopting stone bunds decline with non-irrigated land size. Gbetibouo (2009) found that farm size is positively associated with a high likelihood to uptake adaptation strategies. Moreover, Asafu-Adjaye (2008) found that farm size is positively and significantly associated with soil conservation efforts, while Willy and Holm-Müller (2013) found a negative and significant association between farm size and soil conservation efforts. Farm households that have much of their land located near a river/lake/stream are less likely to plant trees and to practice crop rotations with nitrogen-fixing crops compared to those that have much of their land far from a river/lake/stream. For instance, the less land the farm has that is close to the nearest river, the more likely the farmer is to take up soil conservation (Willy and Holm-Müller, 2013).

Farmers who use tractors are more likely to rely on stone bunds and crop rotations with nitrogen-fixing crops and less likely to use chemical fertilizer and crop rotations with nitrogen-fixing crops compared to those who do not use them. Nonetheless, they are found to be less likely to resort to intercropping with nitrogen-fixing crops. The findings are relatively in line with those of Nhemachena *et al.* (2014). Tractor use is associated with commercialized farmers, and these farmers produce mostly for the market and are relatively specialized. Farm households that use ploughs are less likely to take up intercropping with nitrogen-fixing crops compared with their counterparts that did not use it. Subsistence farm households are more likely to apply less chemical fertilizer and to practice crop rotations with nitrogen-fixing crops compared to the others. As they do not sell a part of their crops to the market, they are obliged to adapt to changes in climate conditions in order to be self-sufficient.

Farmers who are members of farmers' organizations are more likely to resort to stone bunds compared to the others. Kassie *et al.* (2009) found that the decision to adopt sustainable agricultural practices is positively associated with membership in farmers' organizations. Conversely, they are less likely to take up intercropping with nitrogen-fixing crops. In these groups, farmers can discuss among themselves the appropriate adaptation strategies, including sustainable land management practices, to be adopted to cope with the impacts of climate change on their livelihoods. Through these groups, farmers have access to relatively relevant information in terms of appropriate adaptation options, especially those that have the potential to increase crop yields with less impact on the environment. However, these findings suggest that the information farmers have access to through these groups does not support the uptake of all sustainable land management practices.

4. Conclusion and policy implications

This paper analysed the determinants of farmers' perceptions of climate change and those of five sustainable land management practices (planting trees, building stone bunds, using less chemical fertilizer application, rotating crops, and intercropping with nitrogen-fixing crops), using a two-step econometric approach (a binary probit model at the first stage, which is the perception, and a multivariate probit model at the second stage). This modelling procedure allowed for the consideration of the two-stage process of adaptation to changing climatic conditions by accounting for the selection bias. Moreover, it allowed for the simultaneous modelling of the determinants of the five sustainable land management practices identified above, as well as the exploration of the complementarity and substitutability among them.

The findings of the correlation coefficients of the error terms indicated that there are substitutabilities (negative correlation) among three pairs of sustainable land management practices being used by farmers, although these findings could also be due to unobserved farm household socio-economic and other factors. The estimation results revealed that the perception of climate change as a real threat is related positively to land tenure, experience in farming, number of relatives, tractor use, and membership in farmers' organizations, and negatively to household size, remoteness, and plough use. The findings differ with respect to the sustainable land management practices. Overall, the uptake of land management practices is related to assets, land tenure, education level of the household head, remoteness, social network, non-irrigated land size, having the major part of the farm located near a river/lake/stream, tractor and plough use, being a subsistence farmer or not, and memberships in farmers' organizations.

From the findings, we can draw the following policy implications. First, farmers' awareness of climate change can be increased, and the adoption of sustainable land management practices can be strengthened through the promotion of membership in farmers' organizations and of formal and informal social networks that facilitate group discussions on issues related to agriculture and climate, among others. Second, strengthening access to markets by building adequate road infrastructures would enable farmers to obtain improved information crucial to advance their ability to detect changes in climate and to practice sustainable agriculture. Third, policy makers may think about designing programmes that target young farmers in terms of experience, those that rely on rented, leased or community land, households with large family size, and users of ploughs to provide them with information that has the potential to improve their awareness of climate change. These kinds of programs will also be beneficial for those who do not use tractors (who constitute the majority of the agriculturalists of the Niger basin of Benin) to be sensitized on the benefits of sustainable agriculture in improving crop yields and in protecting the environment. Fourth, policies should promote livestock rearing, facilitate land tenure security by vulgarizing the new legal framework on land in the country to help farmers shift from customary tenure to modern tenure, and facilitate the uptake of sustainable agricultural practices. Since all the sustainable land management practices adopted by farmers may not be efficient, future research could assess their effectiveness in mitigating the adverse impacts of climate change on agriculture. Moreover, the rationale behind the adoption of the strategies could be investigated through a qualitative approach.

Acknowledgements

The authors would like to thank the anonymous reviewers and the editor of this journal for providing helpful comments that have substantially improved the quality of the paper. The financial support of the German Federal Ministry of Education and Research (BMBF) through the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) research program is gratefully acknowledged.

References

Ajayi, O.C., 2007. Adoption of renewable soil fertility replenishment technologies in the southern African region: Lessons learnt and the way forward. *Natural Resources Forum*, 31(4): 306–317.

Antle, J.M., Diagana, B., 2003. Creating incentives for the adoption of sustainable agricultural practices in developing countries: The role of soil carbon sequestration. *American Journal of Agricultural Economics*, 85(5): 1178–1184.

Asafu-Adjaye, J., 2008. Factors affecting the adoption of soil conservation measures: A case study of Fijian cane farmers. *Journal of Agricultural and Resource Economics*, 33(1): 99–117.

Branca, G., Lipper, L., McCarthy, N., Jolejole, M.C., 2013. Food security, climate change, and sustainable land management: A review. *Agronomy for Sustainable Development*, 33(4): 635–650. https://doi.org/10.1007/s13593-013-0133-1.

Callo-Concha, D., Gaiser, T., Webber, H., Tischbein, B., Müller, M., Ewert, F., 2013. Farming in the West African Sudan Savanna: Insights in the context of climate change. *African Journal of Agricultural Research*, 8(38): 4693–4705.

Cappellari, L., Jenkins, S.P., 2003. Multivariate probit regression using simulated maximum likelihood. *The Stata Journal*, 3(3): 278–294.

Caviglia, J.L., Kahn, J.R., 2001. Diffusion of sustainable agriculture in the Brazilian tropical rain forest: A discrete choice analysis. *Economic Development and Cultural Change*, 49(2): 311–333.

Deressa, T.T., Hassan, R.M., Ringler, C., 2011. Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science*, 149(01): 23–31.

Di Falco, S., Veronesi, M., 2013. How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics*, 89(4): 743–766.

D'Souza, G., Cyphers, D., Phipps, T., 1993. Factors affecting the adoption of sustainable agricultural practices. *Agricultural and Resource Economics Review*, 22(2): 159–165.

FAO, 2009. *Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies*. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2010. *"Climate-Smart" Agriculture. Policies, Practices and Financing for Food Security, Adaptation and Mitigation*. Food and Agriculture Organization of the United Nations, Rome.

Feder, G., Just, R.E., Zilberman, D., 1985. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, 33(2): 255–298.

Foster, A.D., Rosenzweig, M.R., 2010. Microeconomics of technology adoption. *Annual Review of Economics*, 2(1): 395–424.

Fosu-Mensah, B.Y., Vlek, P.L., MacCarthy, D., 2012. Farmers' perception and adaptation to climate change: A case study of Sekyedumase district in Ghana. *Environment, Development and Sustainability*, 14(4): 495–505.

Gbetibouo, G. A., 2009. Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa. Discussion Paper No. 00849. IFPRI, Washington, DC.

Greene, H.W., 2012. *Econometric Analysis*. Prentice Hall, New York, NY.

Haden, V.R., Niles, M.T., Lubell, M., Perlman, J., Jackson, L.E., 2012. Global and local concerns: What attitudes and beliefs motivate farmers to mitigate and adapt to climate change? *PLoS one*, 7(12): e52882. https://doi.org/10.1371/journal.pone.0052882.

Heckman, J.J., 1976. The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimator for such models. *The Annals of Economic and Social Measurement*, 5(4): 475–492.

Heckman, J.J., 1979. Sample selection bias as a specification error. *Econometrica*, 47(1): 153–161.

IPCC, 2013. Working Group I contribution to the fifth assessment report of the intergovernmental panel on climate change. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M.M.B., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge and New York, NY. pp. 119–158.

IPCC, 2014. Part A: Global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the intergovernmental panel on climate change. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge and New York, NY. pp. 485-533.

Kansiime, M.K., Wambugu, S.K., Shisanya, C.A., 2014. Determinants of farmers' decisions to adopt adaptation technologies in Eastern Uganda. *Journal of Economics and Sustainable Development*, 5(3): 189–199.

Kassie, M., Zikhali, P., Manjur, K., Edwards, S., 2009. Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. *Natural Resources Forum*, 33(3): 189–198.

Kulindwa, Y.J., 2016. Key factors that influence households' tree planting behaviour. *Natural Resources Forum*, 40(1–2): 37–50.

Lasco, R.D., Espaldon, M.L., Habito, C.M., 2016. Smallholder farmers' perceptions of climate change and the roles of trees and agroforestry on climate risk adaptation: Evidence from Bohel, Philippines. *Agroforestry Systems*, 90(3): 521–540.

Lee, D.R., 2005. Agricultural sustainability and technology adoption: Issues and policies for developing countries. *American Journal of Agricultural Economics*, 87(5): 1325–1334.

Lee, L.K., Stewart, W.H., 1983. Landownership and the adoption of minimum tillage. *American Journal of Agricultural Economics*, 65(2): 256–264.

Lin, J.Y., 1991. Education and innovation adoption in agriculture: Evidence from hybrid rice in China. *American Journal of Agricultural Economics*, 73(3): 713–723.

Lokonon, B.O., 2015. *Farmers and Communities Vulnerability and Resilience to Climate Shocks and Adaptation Policy Responses in the Niger Basin of Benin*. West African Science Service Center on Climate Change and Adapted Land Use, Université Cheikh Anta Diop, Senegal.

Louhichi, K., Flichman, G., Boisson, J., 2010. Bio-economic modelling of soil erosion externalities and policy options: A Tunisian case study. *Journal of Bioeconomics*, 12(2): 145–167. https://doi.org/10.1007/s10818-010-9082-9.

Maddison, D., 2007. The perception of and adaptation to climate change in Africa. Policy Research Working Paper No. 4308. The World Bank, Washington, DC

Maponya, P., Mpandeli, S., 2013. Perception of farmers on climate change and adaptation in limpopo province of South Africa. *Journal of Human Ecology*, 42(3): 283–288.

Moyo, M., Mvumi, B.M., Kunzekweguta, M., Mazvimavi, K., Craufurd, P., Dorward, P., 2012. Farmer perceptions on climate change and variability in semi-arid Zimbabwe in relation to climatology evidence. *African Crop Science Journal*, 20(s2): 317–335.

Nhemachena, C., Hassan, R., Chakwizira, J., 2014. Analysis of determinants of farm-level adaptation measures to climate change in Southern Africa. *Journal of Development and Agricultural Economics*, 6(5): 232–241.

Okonya, J.S., Syndikus, K., Kroschel, J., 2013. Farmers' perception of and coping strategies to climate change: Evidence from six agro-ecological zones of Uganda. *Journal of Agricultural Science*, 5(8): 252–263.

Oyerinde, G.T., Hountondji, F.C., Wisser, D., Diekkruger, B., Lawin, A. E., Odofin, A.J., Afouda, A., 2015. Hydro-climatic changes in the Niger basin and consistency of local perceptions. *Regional Environmental Change*, 15(8): 1627–1637.

République du Bénin, 2014. *Analyse Globale de la Vulnérabilité et de la Sécurité Alimentaire*. INSAE, Cotonou.

Roudier, P., Sultan, B., Quirion, P., Berg, A., 2011. The impact of future climate change on West African crop yields: What does the recent literature say? *Global Environmental Change*, 21(3): 1073–1083.

Silvestri, S., Bryan, E., Ringler, C., Herrero, M., Okoba, B., 2012. Climate change perception and adaptation of agro-pastoral communities in Kenya. *Regional Environmental Change*, 12(4): 791–802.

Tanellari, E., Kostandini, G., Bonabana-Wabbi, J., Murray, A., 2014. Gender impacts on adoption of new technologies: The case of improved groundnut varieties in Uganda. *African Journal of Agricultural and Resource Economics*, 9(4): 300–308.

Tilman, D., Cassman, K.G., Maston, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. *Nature*, 418(8): 671–677.

Wiid, N., Ziervogel, G., 2012. Adapting to climate change in South Africa: Commercial farmers' perception of and response to changing climate. *South African Geographical Journal*, 94(2): 152–173.

Willy, D.K., Holm-Müller, K., 2013. Social influence and collective action effects on farm level soil conservation effort in rural Kenya. *Ecological Economics*, 90(June): 94–103.

Yegbemey, R.N., Biaou, G., Yabi, J.A., Kokoye, H.E., 2014. Does awareness through learning about climate change enhance farmers' perception of and adaptation to climate uncertainty? In: Filho, W.L., Alves, F., Caeiro, S., Azeiteiro, U.M. (Eds.), *International Perspectives on Climate Change: Latin America and Beyond*. Springer, Cham, Switzerland. pp. 227–238.

Yegbemey, R.N., Yabi, J.A., Tovignan, S.D., Gantoli, G., Kokoye, S.H., 2013. Farmers' decisions to adapt to climate change under various property rights: A case study of maize farming in northern Benin (West Africa). *Land Use Policy*, 34(September): 168–175. https://doi.org/10.1016/j.landusepol.2013.03.001.