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Determinants of agricultural technology adoption: Farm household's evidence from Niger

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This paper investigates the determinants of agricultural technology adoption decisions taken by Nigerian farm households such as improved seeds, inorganic fertilizers and plant protection products. We use the multinomial probit model on cross-sectional data of 1395 farm households that are representative of farm household in Niger. According to the type of agricultural technology, the results showed that agricultural technology adoption decisions taken by farm households were determined by the age and education level of the farm household head, the size of the farm household, the membership of agricultural cooperative, the number of plots owned, the level of farm household income and wealth, the plot size, the types of soil on the plot, the plots located on the valley and gentle slope, and the land tenure status.

Key words: Adoption, agricultural technology, farm households, multinomial probit, Niger.

INTRODUCTION

According to the United Nations Food and Agriculture Organization (FAO, 2009), to meet people's needs of food worldwide by 2050, it is necessary to dramatically increase agricultural yields, by 70% in relation to their current level. In developing countries, production must double. This increase in agricultural yields is likely to come from the intensification of agricultural production through the use of new agricultural technologies by farmers (FAO, 2009), as the extension of agricultural land becomes increasingly difficult to achieve because of population pressure (FAO, 2012); hence the importance for farmers to adopt agricultural technologies to increase agricultural productivity (FAO, 2009). Feder et al. (1982) defined adoption at individual farmer's level as the degree at which a new technology is used in a long-run equilibrium when the farmer has full information about the technology and its potential.

According to the National Institute of Statistics of Niger (INS), in Niger State, over 80% of the population depends, to a large extent, on agricultural activities (INS, 2014). Despite the importance of the primary sector in the country's GDP, either 42.3% of GDP in 2014 (INS, 2015), Niger's population is confronted with recurrent food insecurity situations. More than 4 million people are affected by food insecurity (INS, 2013). In addition, agricultural productivity and the rate of adoption of agricultural technologies are low in Niger (Asfaw et al., 2015). To increase agricultural productivity, reduce

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poverty and ensure food security in Niger, we try to identify the factors that determine the agricultural technologies adoption decisions taken by farm households. The literature considered agricultural technologies like forage technologies, improved seeds, inorganic fertilizers, land conservation practices, tractors, stall-feeding management, and irrigation technologies with little evidence on the determinants of the plant protection products adoption. In the Nigerian's context, Asfaw et al. (2015) analyzed the determinants of adaptive capacity such as modern inputs, among others. Among the modern inputs, they considered improved seeds and inorganic fertilizers jointly without emphasizing the plant protection products. To fill this gap, in our study, we consider agricultural technologies that help mitigate the risks of crop production related to crop pests such as plant protection products in addition to agricultural technologies that increase agricultural productivity like improved seeds and inorganic fertilizers (De Janvry et al., 2010). In the existing literature, depending on the context and type of agricultural technologies considered, the determinants of the adoption of agricultural technologies are numerous and varied. From these, our question is what are the determinants of the adoption of agricultural technologies by farm households in Niger State?

The contribution of this article is multilevel. First, we use representative sample of agricultural households' data in Niger. Second, unlike most studies on the determinants of adoption of agricultural technologies, the multinomial probit model is implemented. The determinants of the adoption of agricultural technologies are perceptions of farm households of agricultural shocks like climate shocks, crop diseases, locust attack, inputs and food products prices. This article not only extends knowledge of the field by considering these shortcomings but also adds the determinants of the adoption of plant protection products. Also, among the studies carried out in Sub-Saharan Africa, there are very few studies carried out in West Africa, and more particularly in Niger. In addition, our hypothesis is there are explanatory reasons for the adoption of improved seeds, inorganic fertilizers and plant protection products by farm households in Niger.

REVIEW OF LITERATURE

In the theoretical literature on the determinants of the adoption of agricultural technologies, there are intrinsic characteristics of technology and factors that are exogenous and endogenous to the adopter (Rosenberg, 1976; Roussy et al., 2015). The intrinsic characteristics of technology refer to the attributes of technology (Rosenberg, 1976; Roussy et al., 2015). Endogenous factors refer to the adopter's age, experience, education, income and wealth, among others. Among the factors exogenous to the adopter are geographic and climatic factors, institutional factors (Binswanger and Sillers, 1983; Byerlee and De Polanco, 1986; Caswell et al., 1990; Feder et al., 1982; Feder and Slade, 1984; Havens and Flinn, 1976; Hiebert, 1974; Leathers, 1991; Lindner et al., 1979; Yapa and Mayfield, 1978; Just and Zilberman, 1983), socio-cultural factors, political and regulatory factors (Suri, 2011), transport, irrigation, information and communication infrastructures (Feder et al., 1982; Griliches, 1957; Roussy et al., 2015; Sunding and Zilberman, 2001), soil quality, availability of water (Hiebert, 1974), land use (Bhaduri, 1973; Feder et al., 1985; Just and Zilberman, 1983; Newbery, 1975; Scandizzo, 1979) and economic profitability (Feder et al., 1982; Heady, 1952; Just and Zilberman, 1983).

In the empirical literature on the determinants of adoption of agricultural technologies related to our study, some studies analyzed the determinants of improved seeds adoption (Feder et al., 1985; Feder and Umali, 1993; Foster and Rosenzweig, 1995; Gecho and Punjabi, 2011; Kassie et al., 2011; Kohli and Singh, 1997; Minten and Barrett, 2008; Negatu and Parikh, 1999; Ogada et al., 2014; Shapiro et al., 1993; Zeller et al., 1998) and inorganic fertilizers adoption (Duflo et al., 2006; Hailu et al., 2014; Minten and Barrett, 2008; Yanggen et al., 1998) in developing countries. Some studies found that factors such as risk, uncertainty, human capital, plot size, ownership of land, access to credit and work (Feder et al., 1982) and economic profitability (Besley and Case, 1993) determine the agricultural technologies adoption in developing countries.

Foster and Rosenzweig (1995) showed that the adopters' and neighbours' experiences favour the adoption of improved seeds in India. Bindlish and Evenson (1997) found that group membership and extension services determine the adoption of agricultural technologies in Kenya and Burkina Faso. Conley and Udry (2010) and Bandiera and Rasul (2006) also found that social networks and adopters' experience determine the respective adoption of improved varieties of pineapple in Ghana and sunflower in Mozambique. Shapiro et al. (1993) found that economic profitability determines the adoption of improved varieties of millet and beans in Niger. Kohli and Singh (1997) showed that local's conditions, transport, irrigation and communication infrastructure explain the adoption of improved varieties of wheat and rice in the Punjab Region of India. Zeller et al. (1998) found, among other things, that access to credit, agricultural inputs increases the likelihood of adopting hybrid maize in Malawi. The likelihood of adopting hybrid corn declines with market access transaction costs for agricultural inputs (Zeller et al., 1998). Gecho and Punjabi (2011) showed that access to credit, the prices of agricultural inputs, the experience of the farm household's head and the possession of a radio by the farm household, among others, explain the adoption of improved maize in Damot Gale in Ethiopia. Adesina and Baidu-Forson (1995); Adesina and Zinnah

(1993) respectively showed that in Burkina Faso, Guinea and Sierra Leone, the subjective perceptions that farmers have about the characteristics of new sorghum and rice varieties affect their decisions to adopt these agricultural technologies. Negatu and Parikh (1999) found that perceptions of yield and marketing of improved wheat explain its adoption by farmers in Ethiopia. Kassie et al. (2011) found that the size of farms, access to the land market, number of parcels owned by the farm household, the farmers' education level and membership of a local agricultural organization determine the adoption of improved peanut varieties in Uganda. In addition, Duflo et al. (2006) showed that the unsuitability of chemical fertilizers for soils, the inability to save and imperfect information on the profitability and the use of chemical fertilizers explain their non-adoption in Kenya. Hailu et al. (2014) found that off-farm work and contact with vulgarization agents increase the likelihood of adopting chemical fertilizers in Ethiopia. Moreover, land tenure security, irrigation infrastructure, and access to credit increase the likelihood of adopting chemical fertilizers and improved seeds, while this probability decreases for farm households that hold livestock. Ogada et al. (2014) found, among others things, that the expectation of high yield, plot size, and the farm household head's education level determine the joint adoption of inorganic fertilizers and improved maize varieties in Kenya.

On the other hand, the high variability of yields reduces this probability of adoption of inorganic fertilizers and improved varieties of maize. Hailu et al. (2014) and Ogada et al. (2014) showed that males' heads of farm households were more likely to adopt inorganic fertilizers and improved maize than females' heads of farm households. Minten and Barrett (2008) found that literacy rate, secure land tenure and rainfall, among others, explain the adoption of chemical fertilizer, seedling transplanting, improved rice seeds and a new System of Rice Intensification (SRI) in Madagascar. Asfaw et al. (2015) showed that high climate variability and recent climate shocks reduce the likelihood of adopting modern agricultural inputs in Niger. Their results can not only be supplemented by identifying other determinants of agricultural technologies using a multinomial probit model, which requires the exploitation of appropriate data and also fills the gap on the determinants of the adoption of plant protection products.

SURVEY DESIGN AND DATA

Data from the 2014 Survey on Farm households Living Conditions (ECVMA) conducted by the National Institute of Statistics of Niger (INS) with the support of the World Bank are used. The sample was obtained by a two-stage random draw. At the first stage, the counting areas or clusters were drawn with probabilities proportional to their size. 270 enumeration areas or clusters were selected from the 8064 enumeration areas identified in the country. At the second stage, households were drawn with equal probabilities in each enumeration area. In each enumeration area, 30 households were randomly drawn:12 urban and 18 rural households. In total, 4000 households were surveyed. The sample was representative of farm households at the national level. It included households from 8 regions of the country namely Agadez, Diffa, Dosso, Maradi, Tahoua, Tillabery, Zinder and Niamey (the capital).

The investigation was conducted on two field visits. The first visit concerned the planting period, from September to November 2014, and the second visit was made during the harvest period, from December 2014 to February 2015. Three questionnaires were administered for each visit including a household questionnaire, an agriculture/livestock questionnaire and a community questionnaire. The household questionnaire collected information on households' characteristics and socio-demographic characteristics of household members. The agriculture/livestock questionnaire collected data on access to land, plot and field characteristics, and data on perceptions of climate change, among others. The community questionnaire considered data on the existence and accessibility of social services, data on consumer prices. Given the peculiarity of the data from the two visits, the data from the two visits were merged on the corresponding variables to obtain a single database in 2014. We had also merged household, agriculture/livestock and community data on the unique identifier. In total, 4000 households were surveyed. Finally, after data processing, our sample considers 3860 households. Due to the scarcity of livestock data, our study focuses on households engaged in farming and using their plots. Finally, there were 1395 farm households operating 4978 plots.

THEORETICAL, EMPIRICAL AND SPECIFICATION MODELS

Theoretical model

This is the model of farm households where the farm household is rational and risk-averse (Asfaw and al., 2015; De Janvry et al., 2010; Foster and Rosenzweig, 2010, Feder et al., 1985). The objective is to maximize the utility in terms of agricultural profit expected under the constraints of agricultural technologies, constraints of income, labor, constraints of availability of land (Asfaw et al., 2015; De Janvry et al., 2010). The profit function of the farm household can be expressed as:

$$E(\Pi_{t+1}) = Pa_t Qa_t\left(La_t, Ka_{t,} Ta_t\right) - \mathrm{w}La_t - \mathrm{r}Ka_t - \mathrm{l}Ta_t \quad (1)$$

Where $E(\Pi_{t+1})$ represents the expected profit in period t+1, P_{at} and Q_{at}, represent, respectively, the price of agricultural production and the quantity of agricultural products produced in period t. L_{at}, K_{at}, T_{at} are, respectively, the labor, capital and land factors available at period t. w, r, l represent, respectively, the wage rate, the return on capital and the remuneration of the land factor. The farm household adopts agricultural technology when the expected profit is positive. This expected profit can be expressed in terms of utility. So, the decision to adopt agricultural technology comes when the utility (U_{Ai}) associated with the adoption of agricultural technology is greater than the utility (U_{NAi}) associated with the non-adoption of agricultural technology, that is, $U_{A_i} - U_{NA_i} > 0$> 0. The utility of the farm household adopting agricultural technology is $U_{A_i} = X_{A_i} + u_{\mathrm{ai}}$, and the utility of the farm household that does not adopt agricultural technology is $U_{NA_i} = X_{NA_i} + u_{\mathrm{nai}}$. The probability that the farm household i adopts the agricultural technology j on plot l is $P\left(A_{ij}^l = 1/B\,,\Sigma\right) = P\left(U_{\mathrm{Ai}} - U_{N_{Ai}} > 0\right)$ where $P\left(A_{ij}^l = 1\right) = \int_{-\infty}^{A_j} \phi\left(A_i^* / X_{i^{\mathrm{B}}}, \Sigma\right) dA_i^*$ with ϕ the probability density function of the multinomial normal distribution and Σ the variance matrix- covariance. The probability of adopting agricultural technologies according to the distribution function is:

$$P\left(A_{ij}^{l} = 1\right) = F(X'_{i}\text{B}) \quad (2)$$

Where F is the cumulative distribution function, X_i represents the explanatory variables, which is the error term that is normally distributed in a multinomial fashion, whose average is zero and of variance-covariance Σ. Β represents the parameters to be estimated.

Empirical model and specification

The farm household i adopts the technology j on the parcel l (A^l_{ij} = 1) if and only if $A_{ij}^{l^*} = U_{Ai} - U_{NAi} > 0$. Where $A_{ij}^{l^*} = U_{Ai} - U_{NAi} < 0$, farm household i does not adopt technology j on plot l (A^l_{ij} = 1). This can be expressed as follows:

$$A_{ij}^{l} = \begin{cases} 1 & si \;\; A_{ij}^{l^*} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

$A_{ij}^{l^*}$ is a latent variable that is only observed when the farm household makes the decision to adopt or not the agricultural technology. With reference to Maddala (1983), Alvarez and Nagler (1998), Powers and Xie (2000), Asfaw et al. (2015) and De Janvry et al. (2010), we assumed that $A_{ij}^{l^*}$ is a linear function of observable characteristics.

$$A_{ij}^{l^*} = aX_i + \beta Z_k + \mu G_h + u_{ikh} \quad (4)$$

$A_{ij}^{l^*}$ is a function of the characteristics of the farm households X_i, the local characteristics Z_k and the characteristics of the head of farm household G_h, and the error term u_{ikh}, which considers, among other things, the specific unobservable characteristics related to farm households. α, β, μ represent the parameters to be estimated.

To estimate this model, we used the multinomial probit because it is more appropriate to analyze the determinants of the adoption of a set of agricultural technologies (Dorfman, 1996; Alvarez and Nagler, 1998; Dow and Endersby, 2004; Teklewold et al., 2012; Asfaw et al., 2015). The variables to be explained are the dependent variables namely the adoption of improved seeds, inorganic fertilizers and plant protection products. They are discrete variables that take, respectively, the value 1 when the farm household adopts one of them and 0 if the farm household does not adopt any of these agricultural technologies. The explanatory variables are the variables considered in our model.

RESULTS AND DISCUSSION

Descriptive results

The definition of variables and their descriptive statistics are given in Table 1. Among 3860 households, their average age is 48 years old[1]. Men were heads of household in 83% of households, while they controlled household income in only 16% of households. More than 86% of the household's head had no level of education. On average, we had 6 persons in the household. To calculate the wealth and equipment index, we applied the principal component analysis on assets[2] and equipment[3], by keeping the two main axes, respectively. The asset or equipment considered takes the value of 1 if the household held this asset or equipment and 0 if otherwise. The adoption rate of improved seeds, inorganic fertilizers and plant protection products on plots used by farm households represent 2.86, 22.1 and 9.57% on average. The adoption rate of local seeds, crop residues and organic fertilizers is 90.17, 30.04 and 38.75% on average. The average age of the farm household's head is 47 years old. Men were heads of farm household in 90% of farm households, while they controlled farm household income in only 36% of farm households. The average area of land used by farm households was about 2.57 ha. More than 95% of the farm household's head had no level of education. On average, 71.9% of farm households owned the plots they farm.

On average, 71.33% of plots farmed by farm households were on plains. On average, 9.41 and 2.09% of farm households were affected by drought and irregular rainfall and locust attacks, respectively. Higher prices for agricultural inputs affected on average 1.96% of farm households.

Econometric results

We presented the results of the estimation of the multinomial probit model in Table 2. In order to take into account the heterogeneity between the localities, the estimation is carried out by retaining the clusters at the commune level. The likelihood ratio test is significant at 1%. The assumption that there is a correlation between the error terms of the three equations of adoption of agricultural technologies was not rejected. The results showed a positive and significant correlation, on one hand, between adoption decisions for improved seeds and inorganic fertilizers, and, on the other hand, between decisions to adopt inorganic fertilizers and plant protection products. This means that the uses of inorganic fertilizers and plant protection products were complementary, as well as the use of improved seeds and inorganic fertilizers. These results had important implications in terms of agricultural policy.

Among the variables presented in our regression, there were some exogenous and endogenous factors that

[1] The descriptive statistic's table on the 3860 households is available on demand.

[2] The assets considered are armchair, living room, chair, table, dining table, bed, mattress, other furniture, iron, gas stove, kerosene stove, sewing machine, grinder, stove, fireplace, refrigerator, fan, air conditioner , radio, television, video recorder, decoder, car, motorcycle, bicycle, camera, musical instrument, portable, camera, wheelbarrow, computer, group and phone.

[3] Agricultural equipment considered are hoe, machete, "hilaire", shovel, pickaxe, ax, hoe, plow, cart, tractor, yoke, seeder, sprayer, motorcycle pump, powder, watering can, thresher, loft, generator, dryer, huller and livestock.

explained improved seeds, inorganic fertilizers and plant protection products, respectively. We found, moreover, that most of the estimated coefficients had expected signs. The results showed that the use of crop residues and organic fertilizers, the non-food expenditure of the farm household, as well as the membership of a farm household member in an agricultural cooperative and the locust attacks suffered by farm households had positive impact and significant at 1, 5, 5, 10 and 1%, respectively, on the likelihood of adopting improved seeds. In other words, an increase in these different factors had led to an increase in the probability of farm households adopting improved seeds. However, we found that the use of local seeds, higher education level of the farm household's head, size of the farms, drought and irregularity of rains and rise in the prices of agricultural inputs influenced negatively and in a way the probability of farm households adopting improved seeds. The substitutability relationship between the use of improved seeds and local seeds was confirmed. Negative agricultural shocks such as drought, erratic rainfall and rising prices of agricultural inputs led to a decline in the likelihood of farm households adopting improved seeds. Asfaw et al. (2015) also found that climatic variability and negative rainfall shocks led to a decrease in the probability of farm households adopting modern agricultural inputs in Niger. Farm households with plots in the valleys were more likely to adopt improved seeds than plots with gentle and steep slopes, respectively.

Moreover, we found that the use of organic fertilizers, level of secondary education of the farm household's head, farm household size, farm household non-food expenditures, as well as rising prices of agricultural inputs and wealth level of the farm household positively and significantly affected the probability of farm households adopting inorganic fertilizers. We found a complementary relationship between the use of organic and inorganic fertilizers. The same result was obtained by Marenya and Barrett (2007) in their study conducted in Kenya. On the other hand, the age and level of higher education of the farm household's head, as well as the high rate of crop diseases had a negative and significant impact on the probability of farm households to adopt inorganic fertilizers. Farm households with clay-like plots were more likely to adopt inorganic fertilizers than those with silty and glacial plots. Also, farm households whose plots were located respectively on plains and gentle slopes were less likely to adopt inorganic fertilizers than those whose plots were on the valleys. Asfaw et al. (2015) found similar results in their study on the determinants of adoption of climate change adaptation practices in Niger. On the other hand, the use of crop residues and organic fertilizers, as well as the level of wealth and number of plots held by farm households had a positive and significant influence on the probability of farm households adopting plant protection products. Thus, the probability of farm households adopting plant protection products increased, respectively, with the level of wealth and number of plots held by farm households. However, the study level of the farm household's head affected negatively and significantly the probability of farm households adopting plant protection products. According to the sex of the farm household's head, there was no difference in adopting improved seeds, inorganic fertilizers and plant protection products, respectively. There were some characteristics common to farm household that hindered inorganic fertilizers and plant protection products adoption decision.

Although the high rate of crop diseases and locust attacks on farm households had a positive impact on their likelihood of adopting plant protection products, they were insignificant. The results showed that owners and co-owners of plots were more likely to adopt plant protection products than plot occupants in the form of loans, whereas they were less likely to adopt inorganic fertilizers and improved seeds that occupy the plots as a loan.

CONCLUSION AND POLICY IMPLICATIONS

In this study, we used the multinomial probit model on cross sectional data. The data used were representative of farm households in Niger. The results showed that the error terms of adoption decisions for improved seeds, inorganic fertilizers and plant protection products correlated. We found that the uses of inorganic fertilizers and plant protection products were complementary, as well as the use of improved seeds and inorganic fertilizers. There was interdependence, on one hand, between decisions to adopt improved seeds and inorganic fertilizers, and on the other hand, between decisions to adopt inorganic fertilizers and plant protection products. And depending on the type of agricultural technologies considered, the explanatory factors for their adoption were different.

We found that factors such as crop residues and organic fertilizer use, level of wealth and non-food expenditures of the farm household, membership in an agricultural cooperative, and locust attacks experienced by farm households favoured the adoption of improved seeds. However, factors such as the use of local seeds, higher education level of the farm household's head, size and co-ownership of plots, drought, irregular rainfall and high price of agricultural inputs hindered adoption of improved seeds. Moreover, plots located on gentle and steep slopes did not allow the adoption of improved seeds. On the other hand, factors such as organic fertilizer use, farm household's non-food expenditures, wealth and secondary education level of the farm household's head, farm household size, and high prices of agricultural inputs favoured adoption of inorganic fertilizers. The age and level of higher education of the farm household's head, ownership of plots and high rate of crop diseases did not favour the adoption of inorganic

Table 1. Descriptive statistics and definition of variables.

Variable	Sample mean	Definition of variables
Improved seeds	0.0286	1 if the farm household uses improved seeds on the plot, 0 otherwise
Inorganic fertilizers	0.2210	1 if the farm household uses at least one of the inorganic fertilizers on the plot, 0 otherwise
Pesticides	0.0957	1 if the farm household uses at least one of the plant protection products on the plot, 0 otherwise
Local seeds	0.9017	1 if the farm household uses local seed on the plot, 0 otherwise
Culture residues	0.3004	1 if the farm household uses crop residues on the plot, 0 otherwise
Organic fertilizers	0.3875	1 if the farm household uses organic fertilizer on the plot, 0 otherwise
Age of head of farm household	47.8301	Age of the farm household's head in year
Head of farm household (male = 1)	0.8990	1 if the head of the farm household is a man, 0 otherwise
No level of the farm household's head	0.9558	1 if head of farm household has no education, 0 otherwise
Primary level of the farm household's head	0.0384	1 if the head of farm household has a primary level of education, 0 otherwise
Secondary level of the farm household's head	0.0040	1 if the head of farm household has a high school education, 0 otherwise
Higher level of the farm household's head	0.0018	1 if the head of farm household has a higher level of education, 0 otherwise
Farm household size	7.4350	the number of people in the farm household
Income control (man = 1)	0.3608	1 if the person controlling the income in the farm household is a man, 0 otherwise
Wealth index (equipment's axis)	1.1667	Principal component analysis on assets[4] held by the farm household, keeping the two main axis (axis 1 refer to equipment and axis 2 refer to living environment)
Wealth index (living environment's axis)	-0.0487	
Equipment index (axis 1)	-0.9285	Principal component analysis of equipment[5] held by the farm household, keeping the two main axis (axis 1 and 2)
Equipment index (axis 2)	-0.0689	
Non-food expenditure per capita	64454.7299	Farm household's non-food expenditure per capita and per year in cfaF
Food expenditure per capita	136039.9332	Farm household's food expenditure per capita and per year in cfa F[6]
Number of animals kept	5.3158	The number of animals kept by the farm household
Number of plots owned	6.7895	The number of plots owned by the farm household
Member of a cooperative	0.0983	1 if the farm household is a member of an agricultural cooperative, 0 otherwise
Agricultural advice received	0.2467	1 if a member of the farm household received agricultural advice, 0 otherwise
Area of parcels	25782.0407	The area of plots in square meter (m^2)[7] , GPS estimate (*Global Positioning System)*
Sandy	0.7327	1 if the soil of the plot is sandy, 0 otherwise
Slimy	0.0779	1 if the soil of the plot is loamy, 0 otherwise
Clayey	0.1288	1 if the soil of the plot is clay, 0 otherwise
Glacis	0.0606	1 if the soil of the plot is glazed, 0 otherwise
Valley	0.0804	1 if the plot is on a valley, 0 otherwise
Hill	0.0438	1 if the plot is on a hill, 0 otherwise
Plain	0.7133	1 if the plot is on a plain, 0 otherwise
Gentle slope	0.1488	1 if the plot is on a gentle slope, 0 otherwise
Steep slop	0.0137	1 if the plot is on a steep slope, 0 otherwise
Property	0.7190	1 if the plot is occupied as a property, 0 otherwise
Co-property	0.1493	1 if the plot is occupied as a co-ownership, 0 otherwise
Leasing	0.0173	1 if the plot is occupied as a rental, 0 otherwise

[4]The assets considered are armchair, living room, chair, table, dining table, bed, mattress, other furniture, iron, gas stove, kerosene stove, sewing machine, grinder, stove, fireplace, refrigerator, fan, air conditioner , radio, television, video recorder, decoder, car, motorcycle, bicycle, camera, musical instrument, portable, camera, wheelbarrow, computer, group and phone.

[5]Agricultural equipment considered are hoe, machete, "hilaire", shovel, pickaxe, ax, hoe, plow, cart, tractor, yoke, seeder, sprayer, motorcycle pump, powder, watering can, thresher, loft, generator, dryer, huller and livestock.

[6]The monetary unit of which 1 € = 655.957 cfaF, the rate is fixed.

[7]$1m^2=10^{-4}$ha (hectare)

Table 1. Contd.

Mortgage	0.0123	1 if the plot is occupied as a mortgage, 0 otherwise
Loan	0.0986	1 if the plot is occupied as a loan, 0 otherwise
Drought / Irregular rain	0.0941	1 if the farm household has been negatively affected by drought or irregular rainfall in the last 12 months, 0 otherwise
High rate of crop diseases	0.0258	1 if the farm household has been negatively affected by a high t disease crop in the last 12 months, 0 otherwise
Locust Attack	0.0209	1 if the farm household has been negatively affected by a locust attack in the last 12 months, 0 otherwise
Major drop in prices of agricultural products	0.0114	1 if the farm household was negatively affected by a significant drop in prices of agricultural products in the last 12 months, 0 otherwise
High price of agricultural inputs	0.0196	1 if the farm household has been negatively affected by a high price of agricultural inputs in the last 12 months, 0 otherwise
High price of food products	0.0784	1 if the farm household was negatively affected by high food prices in the last 12 months, 0 otherwise
Non-family labor	0.1227	1 if the farm household used non-family labor (employee) on the plot, 0 otherwise
mutual aid	0.0803	1 if the farm household used mutual help on the plot, 0 otherwise
Number of observations	4978	

Source: Authors, ECVMA data, 2014.

Table 2. Determinants of agricultural technologies adoption: multinomial probit estimates.

Variable	Adoption decision		
	Improved seeds	Inorganic fertilizers	Plant protection products
Local seeds	-1.843*** (0.00)	0.064 (0.65)	0.051 (0.73)
Culture residues	0.909*** (0.00)	0.092 (0.31)	0.314** (0.02)
Organic fertilizers	0.323** (0.01)	0.351*** (0.00)	0.350*** (0.00)
Age of farm household's head	0.003 (0.55)	-0.007** (0.01)	-0.004 (0.22)
Head of farm household (Male = 1)	-0.305 (0.30)	-0.103 (0.43)	0.123 (0.32)
Primary level of the farm household's head	-0.678 (0.25)	-0.065 (0.75)	-0.121 (0.65)
Secondary level of the farm household's head	-0.457 (0.36)	0.848* (0.08)	-0.701* (0.09)
Higher level of the farm household's head	-3.336*** (0.00)	-5.753*** (0.00)	-3.354*** (0.00)
Farm household size	0.008 (0.75)	0.042** (0.01)	0.008 (0.75)
Income Control (Male = 1)	0.038 (0.82)	0.081 (0.39)	-0.027 (0.84)
Log (non-food expenditure per capita)	0.440** (0.02)	0.252*** (0.01)	0.047 (0.60)
Log (food expenditure per capita)	-0.239 (0.20)	-0.008 (0.93)	0.302* (0.05)
Wealth index (equipment's axis)	0.160* (0.06)	0.055 (0.16)	-0.053 (0.18)
Wealth Index (living environment's axis)	-0.003 (0.96)	0.193*** (0.00)	0.149*** (0.00)
Equipment index (axis 1)	0.016 (0.80)	0.069 (0.15)	-0.019 (0.70)
Equipment index (axis 2)	0.075 (0.35)	-0.078 (0.13)	0.079 (0.31)
Number of animals kept	-0.033 (0.15)	-0.006 (0.75)	-0.026 (0.16)
Number of plots owned	-0.043 (0.21)	0.005 (0.82)	0.044** (0.04)
Member of a cooperative	0.500* (0.05)	0.182 (0.16)	0.019 (0.93)
Agricultural advice received	0.084 (0.67)	0.066 (0.65)	0.002 (0.98)
Log (area of plots)	-0.087** (0.03)	0.025 (0.39)	0.001 (0.95)
Non-family labor	-0.068 (0.71)	0.114 (0.37)	0.158 (0.23)
mutual aid	-0.186 (0.53)	0.214 (0.13)	0.093 (0.63)
Hill (reference: Valley)	-0.072 (0.81)	-0.361 (0.11)	-0.110 (0.66)
Plain	0.239 (0.22)	-0.317** (0.03)	0.002 (0.99)
Gentle slope	-0.671** (0.01)	-0.357*** (0.01)	-0.046 (0.77)
Steep slope	-3.967*** (0.00)	-0.067 (0.78)	0.120 (0.75)

Table 2. Contd.

Sandy (reference: Clay)	-0.175 (0.26)	-0.095 (0.32)	-0.158 (0.14)
Silty	-0.116 (0.74)	-0.181 (0.23)	0.249 (0.18)
Glacis	-0.378 (0.26)	-0.432** (0.04)	-0.002 (0.98)
Property (reference: Loan)	-0.183 (0.18)	-0.302** (0.04)	0.350** (0.01)
Co-property	-0.524** (0.02)	-0.307 (0.17)	0.466** (0.01)
Leasing	0.582 (0.29)	-0.192 (0.44)	0.422 (0.20)
Mortgage	0.278 (0.52)	-0.248 (0.47)	0.159 (0.67)
Drought / Irregular rain	-1.126** (0.05)	-0.055 (0.730)	-0.250 (0.14)
High rate diseases crops	-0.291 (0.38)	-1.052*** (0.01)	0.179 (0.65)
Locust Attack	1.434*** (0.00)	-0.195 (0.63)	0.478 (0.33)
Major decrease in prices of agricultural products	0.133 (0.89)	-0.117 (0.66)	-0.447 (0.16)
High price agricultural inputs	-4.779*** (0.00)	0.634*** (0.01)	-0.290 (0.33)
High price food products	-0.548 (0.19)	0.150 (0.43)	-0.354 (0.13)
atrho21	0.125** (0.02)		
atrho31	0.076 (0.17)		
atrho32	0.339*** (0.00)		
Constant	-1.548 (0.51)	-3.182** (0.01)	-5.619*** (0.00)
Log-Likelihood pseudo	-2139.26		
Likelihood ratio test	rho21 = rho31 = rho32 =0	chi2(3) = 56.69	Prob> chi2 = 0.0000
Dummy Regions	Yes	Yes	Yes
Number Observations	3,168	3,168	3,168

Source: Authors, ECVMA data, 2014 P- robust values between brackets: * p<0.1; ** p<0.05; *** p<0.01.

fertilizers. In addition, plots on gentle plains and slopes and glacis plots did not encourage the adoption of inorganic fertilizers. Otherwise, we found that the use of crop residues and organic fertilizers, level of wealth, food expenses and number of plots owned by farm households, as well as the ownership and co-ownership of plots allowed adoption of plant protection products.

In terms of agricultural development policy and to promote the adoption of agricultural technologies, emphasis should be put on raising awareness and educating farm household's heads about the benefits of adopting agricultural technologies. Moreover, not only the development of the land market, but also the development of the insurance market for the management of agricultural risks must be allowed, namely drought, irregular rainfall, crop diseases and rising prices of agricultural inputs, among others. Research institutions could further develop agricultural technologies adapted to soil types, as well as soil conservation techniques. However, this paper presented as a limitation the possible recall bias due to the retrospective nature of certain questions for the respondents.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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