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Land tenure and property rights, and the impacts on adoption of climate-smart practices among smallholder farmers in selected agro-ecologies in Nigeria

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Abstract. This study investigates the effects of land tenure and property rights (LTPRs) on smallholder farmers' adoption of climate-smart practices (CSPs) among cereal farming households in Nigeria. The data were collected from maize and rice farmers in a Nation-wide Farm Household Survey conducted across the six geopolitical zones in Nigeria. Data collected were analysed within the framework of Multivariate Probit to determine the factors that facilitate and/or impede the adoption of CSPs. The results showed that the adoption of CSPs considered in this study – agroforestry, zero/minimum tillage, farmyard manure, crop rotation and residue retention - were generally low. Empirical analysis showed that farmers with transfer right were more likely to adopt farmyard manure, crop rotation and residue retention while the likelihood of adopting agroforestry reduced with having transfer right. The coefficient of *de jure* secure increased the likelihood of adopting zero/minimum tillage while the coefficient of control right increased the likelihood of adopting agroforestry. Again, we found that the adoption of zero/minimum tillage reduced with control and transfer rights. The study also contributes to the existing literature on adoption by recognizing the interdependence between different climate-smart practices as well as jointly analyse the decision to adopt multiple CSPs. The study therefore, suggests that governments, in whom the responsibility for land use policy reform lies, review the existing framework to ensure a prompt, fair, and efficient land tenure system.

Keywords: climate-smart practices, Land Tenure and property rights, multivariate probit, smallholder farmers, Nigeria.
JEL codes: Q15, Q18.

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1. INTRODUCTION

Agriculture in the world especially sub-Saharan Africa (SSA) is at a crossroads simply because climate change has brought a menace to the agricultural sector, which must be attended to (IPCC, 2014). Nigeria as one of the African countries is not an exemption in this issue. Climate change poses the greatest challenge to smallholder farmers and threatens the progressive efforts towards poverty alleviation, food security, and sustainable agriculture (Lipper *et al*., 2014; Vermeulen, *et al*., 2011). Globally, smallholder farming households are estimated to be between 475-500 million; cultivating less than 2ha of land (Lowder *et al*., 2016). Many of whom are living in abject poverty and on less than $2 a day, hence, experiencing food insecurity (World Bank Group, 2016; Morton, 2007). Usually, smallholder farmers are the main victims of climate change because of their sole dependency on rain-fed agriculture, limited market access, insecure access to land, cultivation of marginal and fragmented land as well as inadequate access to technical and/or economic support which can help them to embrace resilient-farming practices (Donatti *et al*., 2018; Morton, 2007).

The world's climate is changing fast and will continue to do so for the foreseeable future, no matter what measures are now taken. For agriculture, the change will also be significant, as temperatures rise, rainfall patterns change and pests and diseases find new ranges, posing new risks to agriculture and food systems (Cooper *et al*., 2013). The negative impacts of climate change have led to a reduction in agricultural productivity and substantial welfare losses which eventually lead to food and nutrition insecurity in the populace (Tripathi & Mishra, 2017). Shifting to Climate-smart Agriculture (CSA) seems to be the most efficient way for farmers to reduce the negative impacts of climate change on the production, incomes, and well-being of vulnerable smallholder farmers (McCarthy & Brubaker, 2014).

According to the Food and Agricultural Organization of the United Nations (FAO, 2013), CSA is an unconventional approach to manage land in a sustainable manner while increasing agricultural productivity (World Bank, 2011). It is aimed to achieve three key goals - sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; reducing and/or removing greenhouse gases emissions, where possible (Braimoh, 2015). Climate-smart Practices (CSPs) include inter-cropping, crop rotation, zero tillage, green manuring, application of farmyard manure, integrated soil fertility management, agroforestry, irrigation, changing planting dates as well as alternate wet and dry lowland rice production systems (Bernier *et al*., 2015).

Despite this potential, adoption of CSPs remains generally low, particularly in SSA, Nigeria inclusive. This may, however, not be unconnected with insecure land tenure and property rights (LTPRs), which is often cited as one of the barriers to the adoption of improved technology and investment in land development in Africa (Shittu *et al*., 2021; Byamugisha, 2013; Liniger *et al*., 2011). It is pertinent to note that without secure property rights, farmers often do not have the emotional attachment to the land they cultivate and would thus, not invest in land improvement that can enhance their productivity in the long run and promote sustainable development (Deininger, 2003).

Empirical evidence from the literature corroborates the earlier assertion that adoption of CSPs are generally low in Nigeria, usually between 15.5% – 40.6% (Shittu *et al*., 2018) while the adoption rate for water harvesting, irrigation, and terraces are 15%, 10%, and 30% respectively (Onyeneke *et al*., 2018). They attributed the low adoption to a very weak agricultural extension service delivery system across various states in Nigeria and also to the need for more capital, lack of technical know-how, low potential for irrigation and most importantly present markets cannot accurately account for the value of the environmental benefits that CSA delivers (Ahiale *et al*., 2020; Shittu *et al*., 2018). Gleaning through the literature, some of the factors driving the adoption of the CSPs among smallholders in Nigeria include education, income, credit, extension services, livestock ownership, farming experience, farm size, distance to market and water resources, gender, land ownership, household size, and mass media exposure among others (Oyawole *et al*., 2020; Amadu *et al*; 2020; Aryal et al., 2018).

Arising from the foregoing, using smallholder farmers in selected rice ecologies of Nigeria as a case study, this paper[1] will build on the recent work of Shittu *et al*., (2018) by assessing the influence of LTPRs on the adoption of CSPs. We used multivariate probit (MVP) regression analysis, which explicitly allows for correlation in the error terms of the adoption equations to control for interdependence in decisions on CSPs' adoption. The paper contributes to the ongoing debates on LTPRs and the adoption of CSPs in Africa's smallholder agriculture in a number of ways. First, technology adoption remains one of the most researched areas in the field of agricultural

[1] An earlier version of this paper, titled 'Land Tenure and Property Rights Impacts on Adoption of Climate Smart Practices among Cereals Farmers in Nigeria', was presented at the 18th Annual National Conference of Nigerian Association of Agricultural Economists, October 16th – 19th, 2017.

Table 1. Kinds of rights and tenure security by mode of land acquisition.

Mode of land acquisition	Use right	Control Right	Transfer right	*De facto* Secure	*De jure* secure
Freehold (Inherited & Purchased	√	√	√	√	×
Communal	√	√	×	√	×
Leasehold	√	√	×	×	×

economics, very few studies have looked at the factors that determine the adoption of CSPs in Nigeria. Second, methods that recognise the interdependence between different climate-smart practices and jointly analyse the decision to adopt multiple CSPs - agroforestry, farmyard manure, crop rotation, zero tillage, and residue retention are used. This study attempts to fill these identified gaps.

In the next section, we describe the theoretical framework underpinning the adoption of CSPs and the econometric approach of multivariate probit. Section three (3) presents the methodology in which we have the study area, research design as well as measurement of land tenure and property rights. In section four, we present and discuss the results, while the final section presents the main conclusions and the policy implications.

1.1 Brief on land tenure and property rights in Nigeria

LTPRs have to do with the rights that individuals, communities, families, firms, and other community structures hold in land and associated natural resources. As noted by Feder and Feeny (1991), the rights on the land are "either *de facto* or *de jure* secure" if they are clearly defined, exclusive, enforceable, transferable, and recognized by relevant authorities. In Nigeria, the land use act made provision for granting two types of land use rights - customary and statutory rights of occupancy - to all categories of land users (Land Use Act [LUA], 2004). Customary right of occupancy is granted under the Act by the local government councils to individuals, firms, and communities while the Statutory right of occupancy is the right to use land in any part of the state and it is granted under the Act by the State Governor (LUA, 2004; Kehinde *et al*., 2021). A certificate of occupancy is issued to a land user as evidence of being granted the statutory right of occupancy on the land by the State Governor, thus making the certificate of occupancy the highest form of land title in Nigeria. Issuance of certificate of occupancy requires that the landowner possesses a purchase receipt, duly stamped deed of transfer, and an approved boundary survey of the land. The customary rights of occupancy are governed by the largely unwritten customary laws in various localities and are also considered *de facto* held by holders of agricultural lands in rural areas that have been under use for agricultural purposes prior to the enactment of the Land Use Act of 1979 (LUA, 2004; Shittu *et al*., 2018).

Shittu *et al*. (2018) show that when the land has not been issued a certificate of occupancy, it is subject to unfair expropriation, though the LUA made everybody an occupant of the land. Landowners that acquired their land through direct inheritance and outright purchase enjoy customary rights on their land even though that title is not officially certificated but they are recognized as having a secure title on their land from the customary point of view. Both the latter and the former will enjoy statutory rights of occupancy when the *de facto*-held land is moved to the highest level of tenure security (*de jure* secure) by getting the land surveyed, registered with the state government, and possibly obtain the certificate of occupancy. It is important to note that freehold land is still susceptible to unfair expropriation if it is not registered with the government. Table 1 shows the different land tenure types, possible types of rights with their level of tenure security.

2. ANALYTICAL FRAMEWORK

2.1 Multivariate Probit Model

Multivariate probit regression framework was used to analyze the factors that facilitate or impede the adoption of CSPs, following Scognamillo and Sitko, (2021), Aryal et al., (2018), Kpadonou *et al*., (2017), Timu *et al*., (2013), and Teklewold *et al*., (2013). The model is an extension of the probit model used for the estimation of several correlated binary choices jointly (Greene, 2003).

Considering several agricultural technologies, there is the possibility that some level of interdependence may exist among the technologies with farmers adopting some of these technologies as substitutes, complements or supplements. A farming household would be adopting one or more of the components of CSPs if and only if the utility expected is higher than otherwise. A positive correlation of the error terms means the technologies are complements while negative correlations of the errors terms imply the technologies are substitutes (Teklewood *et al*., 2013; Belderbos *et al*., 2004).

If a correlation exists, simply estimating the technology adoption equations independently will generate biased and inefficient estimates of the standard errors of the model parameters for each technology (Greene 2008), inducing incorrect inference as to the determinants of technology adoption. Dorfamn (1996) observed that the estimates of separate probit equations (univariate probit) exclude useful economic information contained in interdependence and simultaneous adoption decisions. Hence, when farmers adopt a combination of technologies to deal with land degradation rather than adopting just a single practice or technology, the adoption decision is inherently multivariate. Hence, the MVP estimator corrects for these problems by allowing for non-zero covariance in adoption across technologies.

Thus, the observed outcome of CSPs adoption can be modelled following a random utility-based estimation framework. Consider the i_{th} farm household $i=(1,\ldots,N)$ facing a decision on whether to adopt the available CSPs on plot $p(p=1,\ldots,P)$.

Let U_0 represent the benefits to the farmer from traditional management practices, and let U_k represent the benefit of adopting the k_{th} CSPs: *vis-a-vis*, agroforestry (AG), farmyard manure (FY), crop rotation (CR), zero tillage (ZT), residue retention (RR). The farmer decides to adopt the k_{th} CSPs on plot p if $Y^*_{ipk}=U^*_k-U_0>0$.

The net benefit (Y^*_{ipk}) that the farmer derives from the adoption of k_{th} CSPs is a latent variable determined by observed household, plot (Z_{ip}) and socio-economic characteristics X_i and the error term ε_{ip}:

$$Y^*_{ipk}=Z'_{ip}\delta_k+X'_i\beta_i+\varepsilon_{ip} \quad (k=AF,FY,CR,ZT,RR) \tag{1}$$

Using the indicator function, the unobserved preferences in equation (1) translate into the observed binary outcome equation for each choice as follows:

$$Y_{ipk}=\begin{cases}1 \; if \; Y^*_{ipk}>0 \\ 0 \; otherwise\end{cases} \quad (k=AF,FY,CR,ZT,RR) \tag{2}$$

Equation 1 can be rewritten as a system of equations that can be estimated simultaneously using equation 3;

$$\begin{aligned} &Y^*_{1pk}=\beta'_1X_{1i}+Z'_{1i}\delta_k+\varepsilon_{1i} \quad Y_{1pk}=1 \; if \; Y^*_{1pk}>0, \; Y_{1pk}=0 \; otherwise \\ &Y^*_{2pk}=\beta'_2X_{2i}+Z'_{2i}\delta_k+\varepsilon_{2i} \quad Y_{2pk}=1 \; if \; Y^*_{2pk}>0, \; Y_{2pk}=0 \; otherwise \\ &\qquad\qquad\qquad\qquad\vdots \\ &Y^*_{Npk}=\beta'_kX_{ki}+Z'_{ki}\delta_k+\varepsilon_{ki} \quad Y_{Npk}=1 \; if \; Y^*_{Npk}>0, \; Y_{Npk}=0 \; otherwise \end{aligned} \tag{3}$$

In the multivariate model, where the adoption of several CSPs is possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (for identification of the parameters) where ($\mu_{AF},\mu_{FY},\mu_{CR},\mu_{ZT},\mu_{RR}$), MVN $(0,\Omega)$ and the symmetric covariance matrix Ω is given by:

$$\Omega=\begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \cdots & \rho_{1k} \\ \rho_{12} & 1 & \rho_{23} & \cdots & \rho_{2k} \\ \rho_{13} & \rho_{23} & 1 & \cdots & \rho_{3k} \\ \vdots & \vdots & \vdots & 1 & \rho_{4k} \\ \rho_{1k} & \rho_{2k} & \rho_{3k} & \cdots & 1 \end{bmatrix} \tag{4}$$

The off-diagonal elements in the covariance matrix represent the unobserved correlation between the stochastic components of the different types of CSPs. This assumption means that equation (2) generates a MVP model that jointly represents decisions to adopt farming practices. This specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative CSPs[2].

The computation of the maximum likelihood function based on a multivariate normal distribution requires multidimensional integration. Different simulation methods were proposed to approximate such a function (Train, 2002). The Geweke–Hajivassiliou–Keane (GHK) simulator is a particularly popular choice in empirical research (Geweke *et al*., 1997). The GHK simulator exploits the fact that a multivariate normal distribution function can be expressed as the product of sequentially conditioned univariate normal distribution functions, which can be accurately evaluated (Cappellari and Jenkins, 2003). The GHK simulator relies on a Cholesky factorization, and to do this, the estimate of the correlation matrix at each iteration must be positive definite.

3. METHODOLOGY

3.1 The study area

The study was conducted in selected farming communities reputed for maize and rice production across the six geopolitical zones, and covering five of the seven Agro-ecological zones (AEZs) of Nigeria, viz; rainforest zone, derived, southern Guinea, northern Guinea, and Sudan savannah zones respectively. Nigeria is situated

[2] The authors acknowledge that the correlation between the error terms in a system of simultaneous equation depend on the correct specification of the model.

in the West African region and lies between longitudes 3° and 14° and latitudes 4° and 14°. It has a landmass of 923,768 sq. km. Nigeria shares a land border with the Republic of Benin in the west, Chad and Cameroon in the east, and Niger in the north. Its coast lies on the Gulf of Guinea in the south and it borders Lake Chad to the northeast (Udo *et al*., 2018).

Administratively, it is made of 36 Federating States and the Federal Capital Territory. The States are commonly grouped into six geopolitical zones: Northeast, Northwest, North-central, Southeast, Southwest, and South-south geopolitical zones and seven Agro-ecological zones - all of which are suitable for maize and rice, among several other crops like cassava, yams, etc.

3.2 The study design

The study was part of the FUNAAB-RAAF-PASAN-AO project implemented by the Federal University of Agriculture, Abeokuta in partnership with the National Cereals Research Institute, Baddegi, and funded by the Economic Community of West African States. The central focus was on Incentivising Adoption of Climate-Smart Agricultural Practices in Cereals Production in Nigeria. The data were collected across selected agro-ecologies in Nigeria, focusing on maize and rice farmers. The respondents were selected in a three-stage sampling process, described as follows:

Stage I: Purposive selection of 15 States that have been the leading rice and maize producers in Nigeria (excluding conflict-prone areas), based on production statistics from (National Bureau of Statistics [NBS], 2016).

Stage II: Purposive selection of three Agricultural Blocks per State per crop from the main rice and maize producing areas of the State, and two Extension Cells per block - that is, six blocks per state, 12 Cells per State and 180 Cells in all.

Stage III: Proportionate stratified random selection of 12 Rice and maize farmers from members of Rice/Maize farmers' association in each of the selected Cells.

This process yielded 2,007 households of maize and rice farmers, from which complete datasets were collected through personal interviews of the farmer and other farming members of their households. Data were collected on a wide range of issues, including the households' socio-economics, climate-smart practices, and LTPRs on farmland cultivated during the 2016/17 farming season.

Table 2. Adoption rates of climate-smart practices.

Variable	Mean	Std. Error	Min	Max
Agroforestry	0.090	0.005	0	1
Farmyard manure	0.240	0.007	0	1
Crop rotation	0.080	0.005	0	1
Zero/Minimum tillage	0.220	0.007	0	1
Residue retention	0.540	0.009	0	1

3.3 Dependent variables

The outcome variables considered in this study are the CSPs. The respondents were asked to recount the type of CSPs practiced on each of their plots - agroforestry, farmyard manure, crop rotation, zero/minimum tillage, and residue retention (Table 2). Agroforestry refers to the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits. The intentional nature of agroforestry made many of the sampled farmers fall short in this regard; hence, only 9% of the respondents practiced agroforestry on their farms.

Farmyard manure, on the other hand, refers to the application of a decomposed mixture of livestock waste on the farming plot. It is a major component of nutrient management with potential benefits of soil fertility maintenance as well as supply of major nutrients such as Nitrogen, Phosphates, and Potash. Out of the total plots, about 24% of these plots received manure.

Crop rotation involves growing different crops sequentially on the same plot of land to optimize nutrients and reduces the incidence of weeds, pests, and diseases (Bockel *et al*., 2013). In our case, any farmer that plants different crops following a particular sequence and includes a leguminous crop in the rotation was considered as having practiced crop rotation. Based on this concept, only a few of the farmers (8%) practiced crop rotation on their farms.

Zero/minimum tillage is part of CSPs that promotes minimum soil disturbance and allows crop residue to remain on the ground with the accompanying benefits of better soil aeration and improved soil fertility. Minimum soil disturbance requires less traction power and fewer carbon emissions from the soil (Delgado *et al*., 2011). In our case, zero/minimum tillage practice entails reduced tillage with a single plough and/or the use of traditional farm tools such as hoe and cutlass. Zero/minimum tillage was practiced on 22% of the plots.

The use of residue retention is another option of CSPs that provides an opportunity for the farmers to retain crop residues as an alternative to biomass burning and/or exporting the residues from the farm to feed livestock (Bockel *et al*., 2013; Abrol *et al*., 2017). Residue retention was practiced on about 54% of the plots during the cropping season considered for this analysis.

3.4 Independent variables

The description and the summary statistics of the variables are given in Table 3. Specifically, the models include socio-demographic characteristics such as age, sex, year of schooling, household size, extension contact, farmers' association among others.

3.4.1 Socio-demographic characteristics

With respect to socio-demographic characteristics, Table 3 shows that the average age of the smallholder farmers across the six geopolitical zones is 45 years. This implies that the majority of the respondents were still in their active years implying significant participation in the farming activities. This result, however, contradicts the findings of Eze *et al*., (2011) who did a similar study and obtained the mean age of his respondent to be 59 years. Only 12% of the respondents were female indicating that the majority of the sampled smallholder farmers were male. The mean year of schooling is 8 years while those that had access to extension services and belong to one farmers' association or the other were 63% and 94% respectively.

As shown in Table 3, about two-thirds (60.0%) of the respondents have the right to control their land while about 58.0% have the right to transfer their parcels permanently to the third party across the study locations. Table 3 further shows that about half (52.0%) of the parcels were held as inheritance across the study locations, however, this result is much less than the findings of Bamire (2010) who found that 84.0% of farmland was acquired through inheritance in the dry savannah part of Nigeria. On the contrary, about 14.0% of the parcels were purchased by the farm households, 24.0% on leasehold while 10.0% were communal land while only 4.0% of the farmland were titled, i.e., registered with the land registry in the study area. This implies that only a few out of the sampled farmers had legal tenure security while the majority had insecure tenure (*de jure*) which can lead to eviction from their

Table 3. Definitions and Summary Statistics of the Variables Used in the Analysis.

Variable	Description	Mean	SEM
Socio-economic characteristics			
Age	Age of the farmers in years	44.58	0.21
Sex	1 = if the sex of the farmer is female, 0 otherwise	0.12	0.01
Schooling year	Farmers' education level in years	7.74	0.10
Household size	Number of persons in the household	9.25	0.11
Extension Contact	1 = Extension Contact during the last planting season	0.63	0.01
Amount Borrowed	Amount of money borrowed in naira.	99633	11200
Farmers' association	1 = belong to farmers' association, otherwise 0	0.94	0.02
TLU	Tropical livestock unit (Livestock wealth)[1]	3.28	0.23
Plot-level characteristics			
Control right	1 = has control right, 0 otherwise	0.60	0.008
Transfer right	1 = has transfer right, 0 otherwise	0.58	0.008
De jure secure	1 = if registered with the state, 0 otherwise	0.02	0.002
Inherited	1 = cultivates land acquisition by inheritance, 0 otherwise	0.52	0.008
Purchased	1 = land acquisition by purchase, 0 otherwise	0.14	0.01
Leasehold	1 = Land acquisition by leasehold, 0 otherwise	0.24	0.01
Communal	1 = Land acquisition by communal means, 0 otherwise	0.10	0.01
Boundary survey	1 = Has boundary survey, 0 otherwise	0.18	0.007
Farm size (ha)	Cultivated farmland in ha	1.60	0.04
Lowland	1 = cultivates lowland, otherwise 0	0.42	0.01
Extent of farm fragmentation	The extent of land fragmentation computed using Simpson index	0.35	0.01

Note: SEM (Standard error of mean).
[1] TLU conversion factor according to Beyene and Muche (2010): 1 head of cattle = 0.7 TLU, 0.1 TLU for 1 sheep or goat or pigs and 0.01 TLU for poultry.

farmland and regular harassment by land grabbers. A plausible reason for this is that the process of titling land is inexplicably tedious and expensive. Thus, given that most farmers in Nigeria are smallholders and resource poor, they may not allocate their scarce financial resources to land titling. The mean size of household landholdings was 1.60ha portraying the respondents as smallholders. The average farmland that is fragmented is 35% implying that about one-third of the cultivated farmland in Nigeria is not completely consolidated.

3.4.2 LTPRs' measurement

Two indicators were employed in assessing the LTPRs of farmers in this study. They include:

i. Rights Type: This was measured on a nominal scale using three dummy variables – Use, Control, and Transfer rights. Use right refers to the right to access the resource, withdraw from a resource or exploit a resource for economic benefit. Control right on the other hand refers to the ability to make decisions on how the land should be used including deciding what crops should be planted, and who benefits financially from the sale of crops, etc. while Transfer right refers to the ability to transfer land (permanently through sale). Each of the types of rights takes the value of one if the farmer has the right to use, control, and transfer the parcel of land. Otherwise, the dummy variables were assigned a zero. Meanwhile, the use right was dropped as the reference rights-type variable.
ii. *De jure* secure: A tenure was classified as *de jure* secure if the parcel has been surveyed and duly registered with the land registry; otherwise it was classified as insecure. This variable was meant to determine the importance of title registration.

4. RESULTS AND DISCUSSION

4.1 Determinants of adoption of climate-smart agricultural practices

The estimates of the determinants of the probability of adoption of climate-smart agricultural practices are presented in Table 4. The Wald test ($\chi2$ (70) = 404.66; Prob > $\chi2$ = 0.0000) of the hypothesis that regression coefficients in all the equations were jointly equal to zero was rejected at 1% indicating that the model fits the data reasonably well.

The coefficient of transfer right is positive and significant at 1%, 5%, and 10% levels respectively for the adoption of farmyard manure, crop rotation, and residue retention. Hence, transfer right has positive impact on the adoption of farmyard manure, crop rotation, and residue retention, suggesting that farmers are more likely to adopt these CSPs on owned plots. This is in line with the Marshallian inefficiency hypothesis where input use by the tenant on rented or borrowed land is lower or less efficient than on owned land (Gray and Kevane, 2001). This finding may also be due to tenure insecurity, as an insecure tenure status leads to poor agricultural practices (Gray and Kevane, 2001). The long-term dimension of the return on investment in land-enhancing practices such as farmyard manure may discourage land-insecure farmers to adopt them as they may not control the land long enough to reap the benefits of their investments.

Similarly, the coefficient of control right is positive and significant at 10% level for agroforestry, implying that the likelihood of adopting agroforestry rises with farmers' having control right. On the contrary, the coefficient of transfer right is negative and significant at 10% for agroforestry. This implies that having transfer rights reduce significantly the likelihood of agroforestry in the study area. The possible explanation for this might be that farmers are not interested in agroforestry because of its upfront investment that does not yield any immediate returns; they possibly prefer to dispose of the land in the nearest future at a higher price. The result is contrary to the findings of Patanayak *et al*., (2003) who found that landowners are more likely to adopt agroforestry than tenants are because the latter may be prevented from planting trees, as it is less likely that agroforestry will be adopted on insecure land.

Again, we found that the coefficients of control and transfer right significantly and negatively influence the adoption of zero/minimum tillage at 1% level. Security of land tenure, (*de jure* secure), positively and significantly affects the adoption of zero/minimum tillage implying that the probability of adoption of zero/minimum tillage is higher when ownership on land is secure. This flows from the fact that rationally, a farmer may not be willing to adopt any CSPs on land that he/she does not have secure rights to in the long run. As Arthur Young succinctly puts it in his 1792 treatise, "Give a man the secure possession of a bleak rock, and he will turn it into a garden; give him a nine years' lease of a garden, and he will convert it into a desert". This gives credence to the findings of Owombo *et al*., (2015) that secure land tenure significantly influences farmers' adoption of agricultural technology in Ondo State, Nigeria.

The coefficient of farm size is negative and significant at a 1% level for agroforestry. This means that additional hectares of land by the smallholder farmers reduced significantly the possibility of adopting agroforestry; this is simply because the target population for this study is smallholders with an average farm size of 1.60ha. It is also good to note that fragmented farmland does not reduce the adoption of zero tillage in the study area.

The level of education of the cereal farmers has a significant positive relationship with the adoption of crop rotation. This suggests that farmers with higher levels of education are more likely to adopt crop rotation. This finding is consistent with that of Langyintuo and Mekuria (2005) who assert that educated farmers are better able to process information that can enhance production and productivity in agriculture (Ali and Abdulai, 2010). On the contrary, female-headed households are less likely to adopt crop rotation when compared to their male counterparts; this might be because of the level of skill/expertise involved in planting different crops sequentially on the same plot. It is important to note that gender differentiation has no impact on the adoption of any other CSPs. The coefficient for household size is negative and significant at 5% levels for the adoption of crop rotation, suggesting that larger household size is associated with a lower probability to adopt crop rotation. This is consistent with the finding of Bekele and Drake (2003) who find the family size to have a significantly negative relation with certain adoption choices.

The coefficient of farmer's age is positive and significant at a 1% level for the adoption of zero/minimum tillage in Nigeria. This might be because of their farm experience which makes the older farmers be in a better position to adopt new agricultural practices due to their comparative advantage in terms of capital accumulated, frequency of extension contacts/visits, and creditworthiness among others (Langyintuo and Mekuria, 2003). Hence, an experienced farmer is more conscious of the benefits of soil conservation and he would go for adopting the minimum tillage technology. This finding, however, contradicts that of Adesina and Zinnah (1993) who noted that younger farmers are more amenable to change old practices than older farmers because they tend to be more aware and knowledgeable about new technologies. On the other hand, an inverse relationship exists between age and the decision to adopt residue retention among cereals farmers in Nigeria. This can be because the younger farmers are usually more willing to take risks and are likely to perceive increased profits from adoption in terms of accommodating the relative labour-intensive nature that comes with adopting residue retention as against other CSPs (Soule et al., 2000; Aryal et al., 2018; Ekboir, 2003). Hence, the greater willingness to adopt the new agricultural practices.

Meanwhile, the level of education of the cereal farmers has a significant positive relationship with the adoption of zero/minimum tillage, suggesting that farmers with higher levels of education are more likely to adopt zero/minimum tillage. This finding is consistent with that of Shiyani *et al*., (2000) who asserted that education has a positive impact on the adoption of new technology. The role of education enlightens the farming community with the importance of minimum disturbance of the soil in particular.

The adoption of zero/minimum tillage is usually known to reduce the labour required on the farm, hence for larger families where labour is sufficiently available, adoption may not bring many benefit. Hence, the *a priori* expectation is that a larger family size will be inversely related to the adoption of zero/minimum tillage.

Our finding (Table 4) shows a negative relationship between the household size and adoption of zero tillage among the cereal farmers in the study area, indicating that the more the household size, the less likely the adoption of zero/minimum tillage. This is in line with the findings of La Rovere *et al*., (2010) and Laxmi and Mishra (2007).

4.2 Adoption decisions of climate-smart agricultural practices

The MVP model is estimated using the maximum likelihood method on plot-level observations. Table 5 shows the likelihood ratio test [chi square (10) = 161.736, p = 0.000)] of the null hypothesis that the covariance of the error terms across equations is not correlated is rejected. These findings confirm the interdependence between the adoption decisions of CSPs, which may be due to complementarity or substitutability in farming practices, but also potentially, to omitted factors that affect all adoption decisions. Consequently, farmers do not decide upon a single practice to adopt; instead, the probability of adopting a practice is conditional on whether other practices have already been adopted.

The estimated correlation coefficients are statistically significant in seven of the ten pair cases, where five coefficients have negative signs and the remaining two have positive signs. The result shows that farmyard manure is complementary with crop rotation while agroforestry complements residue retention. The complementarity between manure and crop rotation contradicts the finding of Teklewold *et al*., (2013) where they found substitutability. The correlation between adoption of zero/minimum tillage and residue retention is the highest (19.64%) while that of farmyard manure and agroforestry is the least (5.32%). The negative strong correlation between residue retention, zero/minimum tillage,

Table 4. Influence of LTPRs on adoption of climate-smart practices among smallholder farmers: multivariate probit estimates.

	Agroforestry		Farmyard manure		Crop rotation		Zero tillage		Residue retention	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Control right	0.1277*	0.0738	0.0207	0.0576	-0.0134	0.0765	-0.3654***	0.0583	-0.0507	0.0521
Transfer right	-0.1220*	0.0723	0.1839***	0.0573	0.1532**	0.0765	-0.5192***	0.0583	0.0991*	0.0516
Dejure secure	-0.0729	0.2186	-0.2341	0.1780	-0.3115	0.2709	0.3153*	0.1636	0.1504	0.1523
Age	-0.0005	0.0026	0.0014	0.0021	0.0019	0.0028	0.0065***	0.0021	-0.0051***	0.0018
Sex	-0.0517	0.0967	-0.1080	0.0771	-0.2045*	0.1134	0.0817	0.0778	-0.0025	0.0682
Schooling year	-0.0062	0.0053	-0.0075*	0.0041	0.0119**	0.0056	0.0075*	0.0044	-0.0038	0.0038
Household size	-0.0036	0.0048	0.0046	0.0036	-0.0130**	0.0055	-0.0247***	0.0044	0.0045	0.0034
Amount borrowed	-3.39E-08	8.31E-08	-4.84E-08	5.39E-08	3.23E-08	4.73E-08	2.31E-08	5.05E-08	2.88E-08	4.15E-08
Farmers association	0.0111	0.0214	0.0223	0.0166	0.0086	0.0223	-0.0016	0.0182	0.0018	0.0154
Extension contact	-0.0391	0.0638	0.0457	0.0506	0.0071	0.0681	-0.1776***	0.0526	0.0408	0.0456
TLU	-0.0039	0.0046	0.0004	0.0021	0.0037	0.0023	-0.0039	0.0030	-0.0022	0.0020
Farm size	-0.0118***	0.0045	-8.2E-05	0.0027	0.0005	0.0036	-0.0024	0.0029	-0.0017	0.0025
Extent of land fragmentation	-0.0218	0.1085	-0.1780**	0.0834	0.1681	0.1123	0.4113***	0.0885	0.0070	0.0755
Lowland	-0.0147	0.0636	0.0705	0.0496	0.0465	0.0671	-0.0177	0.0528	0.1260***	0.0451
Constant	-1.1136*	0.1594	-0.8917***	0.1250	-1.6749***	0.1722	-0.4639***	0.1298	0.2095*	0.1126
Wald chi-square (70)	404.66		404.66		404.66		404.66	0.0583	404.66	
Log-likelihood	-7452.52		-7452.52		-7452.52		-7452.52		-7452.52	
Prob > chi2	0		0		0		0		0	
Number of obs.	3,311		3,311		3,311		3,311		3,311	

Table 5. Results of the Wald Test of Simultaneity of the decisions to adopt CSPs.

Error correlation[1]	Coefficient	p - value
rho21 (Farmyard manure & Agroforestry)	-0.0532	0.064
rho31 (Crop rotation & Agroforestry)	0.0015	0.969
rho41 (Zero/minimum tillage & Agroforestry)	-0.0747	0.011
rho51 (Residue retention & Agroforestry)	0.1694	0
rho32 (Crop rotation & Farmyard manure)	0.0814	0.047
rho42 (Zero/minimum tillage & Farmyard manure)	-0.1897	0
rho52 (Residue retention & Farmyard manure)	-0.0922	0.001
rho43 (Zero/minimum tillage & Crop rotation)	0.0493	0.192
rho53 (Residue retention & Crop rotation)	0.0346	0.307
rho54 (Residue retention & Zero/minimum tillage)	-0.1964	0

1 Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 =rho43 = rho53 = rho54 = 0.00
Chi-square (10) = 161.736
Prob > chi square = 0

and farmyard manure is logical as the use of one CSP can discourage the adoption of the other one. These findings suggest that using ordinary probit or logit regression to assess the determinants of CSPs adoption among smallholder farmers in Nigeria will yield inefficient estimates. We, however, estimated the model by a set of probit regression (Appendix 1), the result of which shows that the evidence from our study are robust to estimation methods. Though, one will expect that separate probit regression analysis will yield large standard error but we found that the coefficients (βs) and standard errors resulting from each probit regression analysis are the same or nearly the same as that of the multivariate probit estimate. Hence, we conclude that using ordinary probit to assess the determinants of CSPs adoption among smallholder farmers is consistent and asymptotically efficient with large sample (3,311).

5. CONCLUSIONS AND POLICY IMPLICATIONS

This study was carried out to assess the effects of LTPRs on farmers' adoption of climate-smart practices among smallholder farmers in Nigeria. A multi-stage sampling procedure was used to sample 2,007 farm households across 180 farming communities in Nigeria, and data collected were analysed within the framework of Multivariate Probit regression. The results showed that the adoption of CSPs considered in this study – agroforestry, zero/minimum tillage, farmyard manure, crop rotation, and residue retention – were generally low. Policymakers thus need to target practices with lower adoption rates and provide farmers with further incentives towards the intensification of their use.

Another major highlight of this paper is the apparent existence of complementarities between different CSPs such as the use of farmyard manure and crop rotation, use of residue retention, and agroforestry. A potential strategy could be to promote agricultural practices that show some degree of complementarity as a package rather than independently. This may reduce the time required between when the farmer adopts the first technology and the subsequent adoption of other technologies and hence realising the full and extensive benefits of CSPs as a package.

The effects of transfer right on the adoption of farmyard manure, crop rotation, and residue retention are crucial in targeting those farmers that have appropriate socio-cultural characteristics that favour the adoption of the CSPs in question. Secondly, awareness and promotional strategies should be tailored depending on whether the target farmers resemble factors for/against adoption. Our findings confirm that tenure security will increase the likelihood that farmers will reap the returns from the long-term investments such as zero/minimum tillage without unfair expropriation. Therefore, policy measures that will focus on a more effective and efficient land title registration system should be established by the government. This holds important implications for environmental sustainability and climate change adaptation, as farmers will concurrently invest less and try to extract maximum value from land resources if they are unsure about the security of their tenure. As Shittu *et al*., (2018) argue, LTPRs on agricultural lands in Nigeria are mostly informally defined and prone to unfair expropriation, in view of the overriding powers of the State Governor and local governments, as well as the corrupt network of land grabbers. The study suggests that governments, in whom the responsibility for land use policy reform lies, review the existing framework to ensure a prompt, fair, and efficient land tenure system.

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Appendix 1. Influence of LTPRs on Adoption of Climate-smart Practices among Smallholder Farmers: Probit Estimates.

	Agroforestry		Farmyard manure		Crop rotation		Zero Tillage		Residue retention	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Control right	0.1273*	0.0738	0.0183	0.0575	-0.0164	0.0767	-0.3746***	0.0581	-0.0447	0.0522
Transfer right	-0.1214*	0.0722	0.1814***	0.0571	0.1539**	0.0768	-0.5192***	0.0582	0.1010*	0.0517
De jure secure	-0.0747	0.2188	-0.2198	0.1762	-0.2998	0.2688	0.3200*	0.1638	0.1406	0.1522
Age	-0.0005	0.0026	0.0015	0.0020	0.0019	0.0028	0.0066***	0.0021	-0.0051***	0.0018
Sex	-0.0519	0.0967	-0.1080	0.0771	-0.2030*	0.1134	0.0817	0.0778	-0.0069	0.0683
Schooling year	-0.0062	0.0053	-0.0075*	0.0041	0.0120**	0.0056	0.0072	0.0044	-0.0040	0.0038
Household size	-0.0036	0.0048	0.0044	0.0036	-0.0128**	0.0055	-0.0254***	0.0044	0.0044	0.0034
Amount borrowed	-3.18E-08	8.24E-08	-4.71E-08	5.31E-08	3.36E-08	4.72E-08	2.07E-08	5.07E-08	2.97E-08	4.12E-08
Farmers association	0.0114	0.0214	0.0228	0.0166	0.0091	0.0223	-0.0022	0.0182	0.0009	0.0153
Extension contact	-0.0390	0.0638	0.0463	0.0506	0.0085	0.0681	-0.1763***	0.0527	0.0411	0.0457
TLU	-0.0038	0.0045	0.0004	0.0021	0.0037	0.0023	-0.0035	0.0029	-0.0022	0.0020
Farm size (ha)	-0.0119***	0.0045	-0.0001	0.0027	0.0005	0.0036	-0.0024	0.0029	-0.0016	0.0025
Extent of land fragmentation	-0.0208	0.1085	-0.1746**	0.0833	0.1647	0.1125	0.4287***	0.0885	0.0079	0.0756
Lowland	-0.0144	0.0636	0.0715	0.0495	0.0458	0.0671	-0.0202	0.0529	0.1260***	0.0452
Constant	-1.1144***	0.1593	-0.8915***	0.1248	-1.6746***	0.1725	-0.4679***	0.1298	0.2074*	0.1129
LR chi-square (14)	18.35		39.46		32.03		340.93		26.16	
Prob > chi 2	0.1911		0.0003		0.004		0		0.0247	
Log-likelihood	-1004.07		-1789.02		-872.688		-1568.52		-2272.86	
Pseudo R2	0.0091		0.0109		0.018		0.098		0.0057	
Number of obs.	3,311		3,311		3,311		3,311		3,311	