

Article

Understanding the Interdependence and Temporal Dynamics of Smallholders' Adoption of Soil Conservation Practices: Evidence from Nigeria

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Abstract: The adoption of soil conservation practices is widely recognized as essential in improving soil fertility and promoting climate-smart agriculture in general. Yet, smallholders' adoption of soil conservation practices in Sub-Saharan Africa has not been adequately documented, especially in relation to the interdependence and temporal dynamics of adoption decisions. In this paper, we analyze the interdependence and temporal dynamics of smallholders' adoption of soil conservation practices, such as animal manure, crop residue retention, intercropping, and crop rotation in northern Nigeria. We use data from two rounds of a farm-household panel survey among maize-based farming households and estimate econometric models, including pooled multivariate probit and random effects ordered probit. We found that there is a significant positive correlation between the soil conservation practices, suggesting that adoption decisions for these practices are interrelated and the practices are considered complements by the farmers. We found evidence of inter-temporal variability in the adoption of soil conservation practices, which suggests that some farmers do switch in and out of these practices and may likely explain the often-reported variability in maize yields. Also, we found that the farmers' decisions to adopt soil conservation practices and the intensity of adoption are influenced by several factors, including farmer-, household-, farm-, institutional-, and biophysical-level factors. Yet, the factors that significantly influence the likelihood of adoption differ slightly from those that influence the intensity of adoption. Policy interventions to enhance the adoption intensity of conservation practices should strongly leverage important factors, such as contract farming, crop-livestock integration, and off-farm income diversification.

Keywords: adoption; soil conservation practices; pooled multivariate probit model; random effects ordered probit; panel data

1. Introduction

Soil fertility depletion is one of the main biophysical factors that contribute to substantial crop yield gaps in Sub-Saharan Africa (SSA), which poses a threat to achieving food security in the region [1–4]. In particular, it contributes to explaining the low maize yield and economic returns in Nigeria and SSA in general [5–9]. Addressing this challenge through the traditional fallow systems has become almost impossible for smallholder farmers given the decline in per capita landholding associated with rising population pressure, which results in continuous cropping and soil exploitation [10,11]. Soil conservation practices offer smallholder farmers an opportunity to improve soil fertility and sustainably increase yields while also conserving the environment, i.e., these are considered as



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climate-smart practices [12–15]. The adoption of agricultural technologies and management practices is widely recognized in improving the productivity and welfare of farmers, as exemplified in the Asian green revolution [16–19]. Despite the importance of agricultural technologies, particularly conservation practices, such as animal manure, crop residue retention, intercropping, and crop rotation for soil fertility management and climate-smart agriculture, farmers adoption decisions have not been adequately understood. This lends credence to the various studies that have tried to explain the adoption of such conservation practices in the literature over the years in SSA and other developing countries, e.g., [13,20–26]. This also holds for the broader theoretical and empirical agricultural technology adoption literature, e.g., [27–31]. Therefore, a more in-depth understanding of the adoption behavior of farm households is increasingly important, and considered essential to fine-tuning the design and promotion of management practices to drive adoption [26].

Most previous studies on the adoption of conservation practices in Nigeria, e.g., [32–35], and some parts of SSA, e.g., [36–38], examine the adoption of soil conservation practices in terms of a single conservation practice and not multiple practices. This typically ignores the fact that multiple conservation practices may be interrelated and interdependent, and can be influenced by factors relating to their complementarity (synergistic effects) and substitutability (trade-off effects) possibilities [23,26,39]. In addition, most of the documented studies do not consider inter-temporal (year-to-year) variability in the adoption of such soil conservation practices, and the underlying factors that explain the adoption decisions of smallholder farmers across spatially representative production areas. Yet, conservation practices constitute agronomic management practices that can help in explaining the inter-temporal variation in yield and returns to farm investment decisions. This is consistent with some empirical studies on the role of the spatial and temporal heterogeneity in biophysical and socioeconomic conditions of smallholder farmers in constraining soil fertility management [1,4,40,41].

In this paper, we analyze smallholder farmers' adoption of soil conservation practices, such as animal manure, crop residue retention, intercropping, and crop rotation in northern Nigeria. We use data from two rounds of a farm-household panel survey implemented in 2016 and 2017 cropping seasons among 792 maize-based farming households, and we estimate econometric models, including pooled multivariate probit and random effects ordered probit. We contribute to the agricultural technology adoption literature in three ways. First, we add to the documented literature that considered adoption of multiple conservation practices in other SSA countries by providing empirical evidence of the adoption decisions of smallholder maize-based farmers in Nigeria, which has not been adequately addressed. Previous studies have mainly focused on eastern Africa, e.g., [13,15,23,24,42–45]. Second, we contribute to the literature by providing new insights on the temporal dynamics of smallholder maize farmers' adoption decisions in relation to soil conservation practices. In this regard, most previous studies, e.g., [13,24,44–46], only focused on the adoption of soil conservation practices using a static framework, and in turn fail to account for temporal dynamics, which address complementarities and substitutability among different conservation practices adopted over time. Third, we use a spatial sampling framework that allows us to ensure a spatially representative sample of smallholder maize-based systems in the study area. Unlike previous studies that do not utilize a spatially representative sample, our sampling is well designed to enable us provide insights on the adoption decisions of smallholder farmers across space in the maize belt of northern Nigeria, which can improve the external validity of our findings.

2. Materials and Methods

2.1. Study Area and Sampling

The research was conducted in the maize belt of northern Nigeria, specifically in three states - Kaduna, Katsina and Kano (Figure 1). A two-stage sampling design was used to sample households in these states. In the first stage, a spatial sampling framework was adopted whereby 22 sampling grids of 10×10 km were randomly generated across the primary maize areas in the three states with

geospatial inputs using ArcGIS software. This helps to ensure spatially representative maize producing areas in the study area. In defining the grids, the criteria for potential maize intensification were considered, including population density: areas with population density of more than 25 persons per square kilometer and market access: areas with less than four hours of travel time to the nearest urban market. The 22 sampled grids include 99 randomly selected villages in 17 local government areas (LGAs), i.e., the administrative units below the state. In the second stage, a sampling frame of maize-producing households was generated for each of the selected 99 villages. In each of the villages, eight maize-producing households were randomly selected from the sampling frame of maize-producing households, which amounts to a sample size of 792 maize-producing households for the study.



Figure 1. Map of study area.

2.2. Data Collection

We use two-period farm-household panel data from 792 maize farming households. The first round of data collection was in 2016 and the second was in 2017 as part of the Agronomy Panel Survey of the project 'Taking Maize Agronomy to Scale in Africa'. The two survey rounds were implemented using computer-assisted personal interview (CAPI) on open data kit (ODK) software in tablets. The survey instruments consist of plot-, household-, and community-level components. The data collection activities were conducted with the assistance of survey teams comprising of trained enumerators and supervisors. The enumerators were largely graduates of agriculture while the supervisors were affiliated to the International Institute of Tropical Agriculture, Kano, Nigeria, the Centre for Dry-land Agriculture, Bayero University Kano, Nigeria and the National Agricultural Extension Research and Liaison Services, Ahmadu Bello University, Zaria, Nigeria. The language of data collection was mainly the local language of farmers to facilitate farmers understanding of the

survey questions, which allows more accurate responses. The survey instruments were pre-tested to ensure that the instruments can adequately collect the necessary data and to ensure that the survey teams understand the data collection processes.

2.3. Estimation Strategy

We use a pooled multivariate probit (MVP) model to analyze the factors affecting the probability of adopting multiple soil conservation practices, and the random effects ordered probit model to explain the intensity of the adoption of soil conservation practices across the two cropping seasons.

2.3.1. Pooled Multivariate Probit (MVP) Model

The pooled multivariate probit (MVP) model accounts for multivariate adoption decisions in the presence of adoption interdependence. The MVP recognizes the correlation in the error terms of the adoption equations and estimates a set of binary probit models (in our case four probit models) simultaneously. Given that soil conservation practices are not mutually exclusive, the decision to adopt one of the conservation practices may influence the decision to adopt other practice(s). Hence, the application of univariate probit or logit models is inefficient, and would exclude useful economic information about interdependent and simultaneous adoption decisions [13,47,48]. This correlation arises because the same unobserved characteristics of farmers could influence the adoption of different conservation practices. The decision to adopt a particular soil conservation practice may be conditional on the adoption of another complementary practice (positive correlation in the error terms of the adoption equations) or may be affected by the set of substitutes that are available (negative correlation, [47]). However, estimation without considering the trade-offs (substitutability) and synergies (complementarity) of soil conservation adoption leads to biased and inefficient estimates of the determinants of adoption [49].

Theoretically, a specific soil conservation practice is more likely to be adopted if the expected utility derived from its adoption (U_A) is greater than the utility from its non-adoption (U_{NA}) , which is based on the random utility framework. Hence, we assume that an i^{th} maize farming household (i = 1, 2, ..., n) decides at time t = 2016 and 2017, whether to adopt k^{th} soil conservation practice, where k represents the choice of intercropping (IC), crop rotation (CR), manure (MN) and crop residue retention (CRS) on a specific plot if the net utility is positive, i.e., $U_A - U_{NA} > 0$. The household may consider some combination of soil conservation practices as complementary and others as substitutes. If we fail to take into account the correlation in the error terms and the inter-relationships among adoption decisions regarding different practices, it will lead to biased and inefficient estimates [13]. The net utility is defined by a latent variable (y^*_{ikt}) , which is determined by observed factors and the error term, such that:

$$y^*_{ikt} = \beta_i X_{ikt} + u_{ikt} \tag{1}$$

The MVP model is characterized by a set of observed binary dependent variables y_{ikt} , that take a value of 1 if an i^{th} maize-based farming household adopts soil conservation practice k at time t = 2016 and 2017, and zero otherwise, such that:

$$y_{ikt} = \begin{cases} 1 \text{ if } y^*_{ikt} > 0\\ 0 \text{ if otherwise} \end{cases}$$
(2)

where X_{ikt} is a vector of farmer, farm, household, institutional, and biophysical characteristics. β_i is a vector of the estimated parameters of X_{ikt} . u_{ikt} is the error term. In the MVP model, the error terms

jointly follow a multivariate normal distribution with zero conditional mean and variance normalized to unity $(0, \Omega)$ and the covariance matrix (Ω) is given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{IC,CR} & \rho_{IC,CRS} & \rho_{IC,MN} \\ \rho_{CR,IC} & 1 & \rho_{CR,CRS} & \rho_{CR,MN} \\ \rho_{CRS,IC} & \rho_{CRS,CR} & 1 & \rho_{CRS,MN} \\ \rho_{MN,IC} & \rho_{MN,CR} & \rho_{MN,CRS} & 1 \end{bmatrix}$$
(3)

where ρ (rho) denotes the pairwise correlation between error terms. If the correlation of the error terms shown in the off-diagonal elements of the variance-covariance matrix become non-zero, then Equation (2) becomes a multivariate probit (MVP) model. In the estimation of the MVP model, a positive correlation among the different conservation practices is interpreted as a complementary relationship, while a negative correlation indicates that the practices are substitutes [24]. Some empirical studies have applied the MVP in explaining adoption of multiple technologies [13,15,23,24,26].

2.3.2. Random Effects Ordered Probit Model

We estimate the random effects ordered probit model with a dependent variable that takes a value of 0, 1, 2, 3, and 4 respectively, depending on whether a farmer did not use any conservation practice or used one, two, three or four conservation practices in 2016 and 2017 cropping seasons. This is done because the MVP model specified above cannot explain the factors that underlie the intensity of adoption, i.e., the number of practices adopted by the farmers. In explaining the number of soil conservation practices adopted by the farmers, it is often difficult to establish a clear difference between adopters and non-adopters [20,26]. Poisson regression can be used, assuming we take the number of soil conservation practices adopted as a count variable [39]. However, doing so assumes an equal probability of adoption of each alternative conservation practice. This is likely not true in our case study because the probability of adopting a practice might be different from the probability of adopting another. As with the MVP model, the underlying theoretical assumption for the random effects ordered probit model is the random utility framework. The random effects ordered probit model is expressed as:

$$y_{ikt} = \beta_i X_{ikt} + u_{ikt} \tag{4}$$

where $y_{ikt} = (0, 1, 2, 3, 4)$, indicating the number of conservation practices *k* adopted by an *i*th maize-based farming household at time *t* = 2016 and 2017. The ordered nature of the dependent variable (y_{ikt}) is a function of observed heterogeneity (X_{ikt}) with unknown coefficients (β_i) and the error term (u_{ikt}).

Table 1 presents the description of the variables used in the empirical model. The choice of the variables is guided by economic theory and previous empirical findings on agricultural technology adoption [13,15,23,26,29,30,50]. While we considered the dominant soil conservation practices in the maize-based systems in our study area, we note that there are other practices that are applicable to other cropping systems in other areas as reported in previous studies. In addition, the practices we considered are for the focal plot of each household, which is defined as the plot that each household considers as its most important plot in terms of food security and/or income generation.

Variable	Variable Description
	Dependent variable
Adopt animal manure	1 if use of animal manure is practiced by an i^{th} maize farming household, otherwise 0
Adopt intercropping	1 if use of maize-legume intercropping is practiced by an i^{th} maize farming household, otherwise 0
Adopt crop rotation	1 if use of crop rotation (rotation of maize with other crops) is practiced by an <i>i</i> th maize farming household, otherwise 0
Adopt crop residue retention	1 if use of crop residue retention is practiced by an i^{th} maize farming household, otherwise 0
Intensity of adoption	Number of conservation practices adopted by an i^{th} maize farming household (0, 1, 2, 3, 4)
	Independent variable
Age	Age of farmer in years
Household size	Adult equivalent household size
Farm size	Total size in hectares of farmland owned
Farming experience	Years of experience in farming activities
Extension contact	Number of contacts with extension agents
Membership of association	1 if yes, otherwise 0
Maize contract	1 if farmers had access to contract farming, otherwise 0
Livestock ownership	Tropical livestock units (TLU)
Access to off-farm income	1 if yes, otherwise 0
Access to credit	1 if yes, otherwise 0
Number of fields	Total number of fields cultivated by farmers
Use inorganic fertilizer	1 if farmer applied inorganic fertilizer, otherwise 0
Weeding	Number of times weeding is done on maize fields
Ownership of mobile phone	1 if farmer owns a mobile phone, otherwise 0
Rainfall	Annual amount of rainfall in mm.

Table 1. Description of variables used in estimation.

3. Results and Discussion

3.1. Descriptive Results

Table 2 presents the farmer-, farm-, and household-level characteristics of the maize producing households. The results show that the average age of the farmers was about 44 years, with average farming experience of 19 years. The average household size was about 9 persons, and each household owns livestock equivalent to 2.14 tropical livestock units. The average farm size was about 3.11 hectares, with average area allocated to maize to be around 0.82 hectares. The households own on average three maize fields, and the average number of contacts with extension agent was 1.17 contacts. Data on climate-related variables were also collected from the closest weather stations to each of the villages. On average, the annual temperature was about 26.23 °C while the average annual rainfall was 975.79 mm.

Table 2. Summary statistics of farmers' characteristics.

Variables	Mean	Standard Deviation
Age (years)	44.24	11.9
Years of education	5.20	6.09
Adults (no)	3.44	1.86
Children (no)	5.68	4.34
Household size (no)	9.12	5.44
Farming experience (years)	18.96	10.48
Farm size (ha)	3.11	3.46
Maize fields (no)	2.70	1.17
Maize focal plot (ha)	0.82	0.99
Extension contacts (no)	1.17	2.05
Livestock ownership (TLU)	2.14	4.23
Use inorganic fertilizer (yes $= 1$)	0.74	0.44
Ownership of mobile phone (yes $= 1$)	0.89	0.30
Number of weeding	2.04	0.57
Maize contract (yes $= 1$)	0.19	0.39
Membership of association (yes $= 1$)	0.31	0.46
Amount of credit (₦1000)	69.14	96.16
Total assets owned (₦1000)	545.66	811.48
Rainfall (mm)	975.79	157.63
Temperature (°C)	26.23	0.65

Based on the panel dataset, four different soil conservation practices, namely intercropping, crop rotation, animal manure and crop residue retention, were considered. Figure 2 shows that the rate of adoption of animal manure was highest among the conservation practices across the 2016 and 2017 cropping seasons. However, there was a downward trend in the adoption rate from 76% in 2016 to 69% in 2017. This was closely followed by crop residue retention of 73% in 2016, but had a larger drop to 46% in 2017. The high rate of adoption of animal manure across the two years corroborates the findings of [51], who showed that organic manure had the highest level of usage among soil conservation practices in south-eastern Nigeria. However, the result is not consistent with the findings of [52], where crop rotation was found to have the highest rate of adoption in north central Nigeria.



Figure 2. Rates of adoption of soil conservation practices in 2016 and 2017 cropping seasons.

The rate of adoption of maize-legume intercropping across the 2016 and 2017 cropping seasons was low compared to the adoption of animal manure and crop residue retention. Unlike the latter, there was an upward trend in the rate of adoption of maize-legume intercropping from 28% in 2016 to 32% in 2017. Strikingly, the adoption rate of crop rotation was the lowest among all the conservation practices, and had a similar downward trend observed in the use of animal manure and crop residue retention. The adoption rate dropped from 16% in 2016 to 12% in 2017 (Figure 2). The low adoption of crop rotation is in contrast with the findings of [53], where the adoption of crop rotation was found to be the highest in rural Ethiopia. Overall, the results indicate that there is inter-temporal variability in the adoption of soil conservation practices, which suggests that some farmers do switch in and out of these practices and may likely explain variability in yields. In addition, the results indicate that the use of animal manure is common in the study area despite the observed variability between the two years. This is likely because it is a low-cost, low-risk input in comparison with inorganic fertilizer, and some farmers rely on it as a substitute or complement to inorganic fertilizer [54]. It also increases water filtration and water holding capacity of soils, increases soil organic matter, promotes soil biological activities, and aids soil aeration [51,55]. We also considered the conditional probabilities in the adoption of the various conservation practices in the study area (Table A1 in the Appendix A). The results show that the conditional probabilities in the adoption of the practices were significantly greater than the unconditional probabilities, suggesting greater complementarity and less substitution among the practices in both 2016 and 2017 cropping seasons [39,56].

Figure 3 shows the distribution of the number of conservation practices adopted by the farming households in 2016 and 2017 cropping seasons. The adoption of two conservation practices was more common across the 2016 and 2017 cropping seasons. This suggests that farmers prefer the combination of two conservation practices on their maize fields irrespective of the cropping season. This may be as a result of the synergistic advantage of combining conservation practices. The result supports earlier findings of [53], where the intensity of adoption of two conservation practices was the highest among farmers in Ethiopia. However, there was a downward trend in the adoption of two practices from 33% in 2016 to 29% in 2017. This was closely followed by the adoption of three conservation practices with a stable adoption level of about 25% in both 2016 and 2017 cropping seasons. The adoption of four practices in the two years was slightly low compared to the adoption of two and three practices. Just like the former, there was a downward trend in the adoption of four practices from 20% in 2016 to 13% in 2017 cropping season. The results suggest that there is some sort of complementarity in the adoption of multiple conservation practices in both 2016 and 2017 cropping seasons. Overall, our results are not consistent with the findings of [57], where the majority (55%) of the farmers in south-west Nigeria did not adopt any conservation practice, 35% adopted one practice, and 5% adopted two and three practices. In terms of the actual combinations of practices adopted by the farmers (Table A2 in the Appendix A), the majority of the farmers adopted the combination of animal manure and crop residue retention in both years. Also, the results show that, except for combined intercropping and animal manure, there is inter-temporal variation in the combinations of soil conservation practices adopted by the farmers, which may likely contribute to explaining inter-temporal variation in maize yields.



Figure 3. Intensity of adoption of soil conservation practices in 2016 and 2017 cropping seasons.

3.2. Factors Influencing the Rate of Adoption of Soil Conservation Practices

Table 3 shows the pair-wise correlation coefficients across the residuals of the estimated pooled multivariate probit (MVP) model. Most of the estimated pair-wise correlation coefficients across the residuals of the MVP model were statistically significant, which supports the null hypothesis that the error terms of the multiple adoption decision equations are correlated. The likelihood ratio test (Chi² (6) = 21.621; Prob > Chi² = 0.000) also rejected the null hypothesis that the covariance of the error terms across equations are not correlated. This justifies the rationale for using the MVP model, and confirms that the adoption of multiple soil conservation practices in the study area is not mutually exclusive. The correlation coefficient for the use of intercropping and crop rotation

was positive and significant, implying that the farmers consider these conservation practices as complements. Likewise, other combinations such as intercropping and crop residue retention, and crop residue retention and animal manure were also positive and significant, which indicates that the farmers consider these conservation practices as complements. In support of the complementarities of soil conservation practices, empirical studies, e.g., [13,15,23,24,26,44,45,53,58], found a positive and significant association (complementarities) between combinations of soil conservation practices, which suggests that their adoptions are interrelated.

Table 3. Estimated covariance matrix of the regression equations between the conservation practices using the pooled MVP model.

	Intercropping	Crop Rotation	Crop Residue Retention		
Crop rotation	0.124 (0	.062) **			
Crop residue retention	0.132 (0.041) ***	0.07	0 (0.055)		
Animal manure $-0.005 (0.045)$		-0.081 (0.065)	0.090 (0.045) **		
Likelihood ratio test of $rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0$					
Chi^2 (6) = 21.621 *** Prob > Chi^2 = 0.000					
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Note: *** Significant at 1%, ** Significant at 5%, Standard errors reported in parenthesis.

The result of the estimated pooled MVP model is presented in Table 4. The results show that the model fits the data well as the Wald test (Wald Chi^2 (52) = 2205.930; Prob > Chi^2 = 0.000) rejects the null hypothesis that there is no significant relationship between the farmer-, farm-, and household-level characteristics of the maize producing households, and their adoption decisions. This shows the relevance of the model to account for the unobserved correlations across the adoption equations for multiple conservation practices. In other words, the effects of the explanatory variables on the probability to adopt differ substantially by the respective soil conservation type.

The results show that the age of farmers significantly influence their decision to adopt some of the soil conservation practices. Specifically, the age of farmers is positively related to the probability of adopting crop rotation at 5% significance level but negatively related to the probability of adopting animal manure at 10% significance level. This implies that older household heads are more likely to adopt crop rotation, and also less likely to use animal manure. The reduced probability of adoption of animal manure when age increases is in consonance with the findings of [33] and [59]. However, [53] found that age significantly increases the probability of adoption of animal manure. Also, the results of [60] showed that age of household head was not significantly related to the adoption of any soil conservation practice. In other words, there are mixed findings on correlation of farmer age with the adoption of manure in the literature and our result adds to the literature by aligning with the previous studies that report a negative correlation. A plausible reason for the negative correlation may be due to limited access to manure, and/or higher manpower needed for transportation of manure from the homestead to the farm and for application of the manure on the farm. Access to contract farming arrangement is significantly related to the adoption of the soil conservation practices except for animal manure. Specifically, households involved in maize contract farming are more likely to adopt crop rotation. The increased probability of adoption of crop rotation is likely because they may have more plots to allow of easy rotation, as a way to improve soil fertility and suppress build-up of soil-borne diseases amongst others [61,62]. Also, the results indicate a reduced probability to adopt both intercropping and crop residue retention. This suggests that, with more access to external inputs, such as fertilizer via a contract scheme, farmers may not see the need for intercropping and residue retention to improve soil fertility.

Household livestock ownership is found to significantly influence the decision to adopt the soil conservation practices. Households with more livestock units have a higher probability of adopting manure and crop residue retention. Manure and crop residues are the main sources of organic nutrients in the smallholder crop-livestock or crop-tree-livestock farming systems in the tropics and subtropics and contribute to nutrient cycling [63,64]. The increased likelihood of adopting animal manure is

in line with a priori expectation, as farmers with more livestock units are more likely to use animal manure on their maize fields. Also, this can generate greater biomass for residue retention on the fields and to feed their livestock [33]. This result is in consonance with empirical findings of [13,26,65]. The positive correlation of ownership of livestock and the adoption of crop residue retention corroborates the findings of [66] and [60], where livestock holdings significantly increased the likelihood of adoption of residue retention as a single practice, and in combination with crop rotation. This is plausible as larger livestock holdings can increase the availability of manure and in turn increase the application of manure, which can increase the availability of biomass for on-farm retention. The farming experience of the farmers significantly influenced their decision to adopt crop rotation. Specifically, the probability of adopting crop rotation is less likely with a higher farming experience, which indicates that they have more tendencies to continue cultivating maize on the focal plot in every cropping season. The result corroborates the findings of [67] where farming experience influenced farmers' adoption of soil conservation among crop-based farmers.

Access to off-farm income sources is significantly related to the likelihood of adopting only crop residue retention. This indicates that households generating income outside farming activities have a higher probability of adopting crop residue retention. It is noteworthy that engagement in off-farm activities can promote the adoption of soil conservation practices as cash availability is considered as one of the important constraints in agricultural production. On the other hand, the practices are not capital intensive compared with external inputs, such as inorganic fertilizer, which may contribute to explaining the lack of correlation with most of the practices. The result is consistent with the findings of empirical studies, e.g., [15,68,69]. Access to credit is significantly associated with the adoption of the soil conservation practices with the exception of crop residue retention and crop rotation. In particular, farm-households who had access to credit are more likely to adopt manure, but less likely to adopt intercropping. This is plausible as the adoption of animal manure is likely more capital intensive relative to the other conservation practices and farmers may continue cultivating maize if they have access to credit that will allow them to invest in manure and other inputs. The influence of access to credit on farmers' decision to adopt conservation practices supports the findings of [60], where access to credit influenced the adoption of crop rotation and crop residue retention. In addition, [26] show that access to credit significantly increases the likelihood of adoption of crop residue retention, and reduces the likelihood of adoption of crop diversification.

The use of inorganic fertilizer is significantly associated with the decision of farmers to adopt animal manure. Specifically, the use of inorganic fertilizer was associated with a reduction in the probability of adopting animal manure. A plausible explanation for this result could be that some farmers consider inorganic fertilizer and manure as substitutes rather than as complements. This may be because inorganic fertilizers contain substantially higher amounts of nutrients, especially macro-nutrients for cereal crop performance which are readily available to crops than that from organic sources [4,64,70]. Yet, this result is not in tandem with the expected complementary use of organic and inorganic fertilizer within the framework of integrated soil fertility management practices [1,71]. The result also negates the findings of [55], where the application of inorganic fertilizer marginally increased the adoption of animal manure. However, the lack of complementary use of organic and inorganic fertilizer is consistent with the findings of [56]. The application of more weeding is significantly related with the decision of farmers to adopt all the soil conservation practices with the exception of intercropping. The result shows an increased probability of adoption of crop rotation, manure and crop residue retention respectively by households who undertake frequent weeding. This is plausible because farmers who properly weed their fields as a good agronomic practice are more likely to use other good agronomic practices, such as crop rotation, animal manure and retention of crop residue [72].

Variables	Intercropping	Crop Rotation	Manure	Crop Residue Retention
Age	0.003 (0.004)	0.012 (0.006) **	-0.008 (0.004) *	0.001 (0.004)
Extension contact	-0.009 (0.016)	0.003 (0.023)	0.026 (0.022)	0.001 (0.017)
Maize contract	-0.393 (0.107) ***	0.355 (0.135) ***	0.057 (0.122)	-0.219 (0.104) **
Household size	-0.021 (0.020)	-0.035 (0.038)	0.023 (0.023)	0.012 (0.021)
Member association	-0.062 (0.075)	-0.009 (0.117)	0.092 (0.085)	-0.064 (0.077)
Livestock ownership	0.005 (0.013)	0.025 (0.019)	0.066 (0.022) ***	0.028 (0.013) **
Farm size	-0.008 (0.010)	-0.018 (0.018)	0.002 (0.011)	-0.013 (0.009)
Farming experience	-0.003 (0.004)	-0.017 (0.007) ***	0.007 (0.005)	-0.004 (0.004)
Off-farm income	0.131 (0.101)	0.116 (0.167)	0.178 (0.111)	0.468 (0.101) ***
Access to credit	-0.158 (0.078) **	-0.187 (0.123)	0.167 (0.090) *	0.123 (0.080)
Mobile phone	-0.121 (0.116)	0.121 (0.197)	-0.015 (0.129)	0.094 (0.117)
No of fields	0.039 (0.032)	0.009 (0.049)	-0.023 (0.036)	0.011 (0.033)
Fertilizer	0.179 (0.229)	-0.274 (0.281)	-4.886 (0.152) ***	-0.338 (0.228)
Weeding	-0.053 (0.061)	0.179 (0.097) *	0.198 (0.073) ***	0.165 (0.064) ***
Rainfall	0.198 (0.199)	1.961 (0.419) ***	-0.517 (0.229) ***	0.844 (0.205) ***
_constant	-1.537 (1.410)	-15.261 (3.009) ***	8.623 (1.617) ***	-5.994 (1.451) ***
Regression diagnostics				
Log pseudo likelihood	-2847.581			
Wald Chi ² (52)	2205.930 ***			
$Prob > chi^2$	0.000			

Table 4. Estimates of the pooled multivariate probit (MVP) model of the likelihood of adoption of soil conservation practices.

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%, Standard errors reported in parenthesis.

The amount of rainfall significantly influenced the decision to adopt soil conservation practices with the exception of intercropping. The result shows that there was higher probability in the adoption of crop rotation and crop residue retention, and reduced probability in the adoption of manure. This suggests that farmers do consider expected climatic conditions, especially rainfall in their choice of crop management practices and this is plausible because the production system is fully rain-fed. This is largely consistent with previous studies, e.g., [15,26,39] that show that rainfall influences farmers' adoption decisions in relation to conservation practices. Also, the result supports the findings of [13] where rainfall was found to significantly increase the probability of adoption of crop rotation, but reduced the probability of adoption of intercropping.

The number of contacts with extension agents, adult equivalent household size, membership of association, farm size, number of maize fields and ownership of mobile phones were not significantly related with the decision to adopt soil conservation practices in the study area. This is consistent with some studies on adoption of conservation practices on one hand but not consistent with other studies on the other hand. For instance, [60] found that large farm size significantly decreases the probability of adopting crop residue retention but increases the likelihood of adopting crop rotation. [13] found that farm size significantly reduces the likelihood of adoption of intercropping, but increases the probability of adoption crop rotation. [26] found that membership of association influenced farmers' decision to adopt soil conservation practices. Consistent with our results, [39] found out that the ownership of mobile phones did not significantly influence the likelihood of adoption of soil conservation practices. Meanwhile, [69] found that the number of contacts with extension agent significantly influenced farmers' decision to adopt climate-smart practices.

3.3. Factors Influencing the Intensity of Adoption of Soil Conservation Practices

Table 5 shows the results of the estimated random effects ordered probit model. The chi-square statistic is statistically significant (Wald Chi² (15) = 71.28; Prob > Chi² = 0.000). This justifies the rationale for using ordered probit model and confirms that intensity of adoption is jointly influenced by the explanatory variables. The results show that a household's participation in contract farming arrangement increases the marginal probability of adopting more than one conservation practice by 6.4%. This is plausible because contract farming is an important channel for farmers to have access to credit, inputs and output market, and information about new technologies, etc. [13,73]. Households with more livestock units are 1.3% more likely to adopt more than one conservation practice. A plausible explanation for this is that the wastes from livestock serve as manure, which helps to improve soil quality and crop yield. This corroborates the findings of [26], whereby households with livestock holdings were 8% more likely to adopt more than one soil conservation practice. The important role of livestock ownership suggests that integrating livestock into the cropping systems can help to improve the adoption intensity of soil conversion practices.

Farm size has a negative and significant influence on the number of practices adopted and, specifically, households with a smaller farm size are 0.8% less likely to adopt more than one conservation practice. This lends credence to the inverse farm size-productivity relationship of empirical studies, such as [74] as small farms who are more likely to use more conservation practices may realize productivity gains through such practices. The result supports the findings of [75], where farm size was found to significantly influence the intensity of adoption of conservation practices. Access to off-farm income was found to positively and significantly determine the intensity of adoption. Households with access to off-farm income are 6.9% more likely to adopt two or more conservation practices. Households with access to off-farm income may be better able to adopt technologies because they are less likely to face liquidity constraints [13], which lends credence to the promotion of income diversification for multiple benefits to farmers, including technology adoption. Yet, this result is in contrast with the findings of [15] who showed that off-farm income significantly reduced the intensity of adopting more than two practices by 14%.

Variables	Coefficients	Marginal Effects				
		$\Pr\left(Y=0/X\right)$	$\Pr(Y = 1/X)$	$\Pr\left(Y=2/X\right)$	$\Pr\left(Y=3/X\right)$	$\Pr\left(Y=4/X\right)$
Age	0.003 (0.004)	-0.001 (0.001)	-0.001 (0.001)	0.000 (0.000)	0.001 (0.001)	0.000 (0.000)
Extension contact	-0.008 (0.012)	0.001 (0.002)	0.002 (0.002)	-0.001 (0.001)	-0.002 (0.003)	-0.000 (0.000)
Maize contract	-0.184 (0.088) **	-0.028 (0.014) **	-0.035 (0.017) **	-0.018 (0.009) **	0.042 (0.020) **	0.004 (0.002) *
Household size	-0.027 (0.018)	0.004 (0.003)	0.005 (0.003)	-0.003 (0.002)	-0.006 (0.004)	-0.001 (0.000)
Association	0.004 (0.071)	0.001 (0.011)	0.001 (0.014)	-0.000 (0.007)	-0.001 (0.016)	-0.000 (0.001)
Livestock ownership	0.038 (0.012) ***	-0.006 (0.002) ***	-0.007 (0.002) ***	0.003 (0.001) ***	0.009 (0.003) ***	0.001 (0.000) **
Farm size	-0.023 (0.008) ***	0.004 (0.001) ***	0.005 (0.002) ***	-0.002 (0.001) ***	-0.005 (0.002) ***	-0.001 (0.000) **
Farming experience	-0.003 (0.004)	0.001 (0.001)	0.001 (0.001)	-0.000(0.000)	-0.001 (0.001)	-0.000(0.000)
Off-farm income	0.197 (0.088) **	-0.030 (0.014) **	-0.038 (0.017) **	0.019 (0.009) **	0.045 (0.020) **	0.004 (0.002) *
Access to credit	-0.069 (0.070)	0.011 (0.011)	0.013 (0.013)	-0.007(0.007)	-0.016 (0.016)	-0.001 (0.001)
Mobile phone	0.139 (0.099)	-0.021 (0.015)	-0.027 (0.019)	0.014 (0.010)	0.032 (0.023)	0.003 (0.002)
No of maize fields	0.019 (0.026)	-0.003 (0.004)	-0.004(0.005)	0.002 (0.003)	0.004 (0.006)	0.000 (0.001)
Fertilizer	0.344 (0.61) **	-0.053 (0.025) **	-0.066 (0.031) **	0.034 (0.017) **	0.078 (0.037) **	0.007 (0.004) *
Weeding	0.189 (0.058) ***	-0.029 (0.009) ***	-0.036 (0.011) ***	0.019 (0.006) ***	0.043 (0.013) ***	0.004 (0.001) ***
Rainfall	0.954 (0.201) ***	-0.147 (0.030) ***	-0.183 (0.037) ***	0.096 (0.021) ***	0.217 (0.043) ***	0.018 (0.006) ***
Threshold parameters						
Cut1_cons	5.390 (1.392) ***					
Cut3_cons	6.471 (1.409) ***					
Cut3_cons	7.795 (1.429) ***					
Cut4_cons	9.490 (1.465) ***					
Wald Chi ²	71.28 ***					
$Prob > Chi^2$	0.000					
Log Pseudolikelihood	-1732.13					

Table 5. Estimates of random effects ordered probit of the determinants of the intensity of adoption of soil conservation practices.

Note: *** Significant at 1%, ** Significant at 5%, * Significant at 10%, Standard errors reported in parenthesis.

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Inorganic fertilizer application significantly influenced the intensity of adoption of soil conservation practices with 11.9% marginal probability of adopting more than one conservation practice. A plausible explanation for this is because of the synergistic effects of the combined use of inorganic fertilizer and more conservation practices. In other words, the use of more conservation practices helps to build soil organic matter, which improves soil quality and efficiency of inorganic fertilizer use leading to improved yield response to fertilizer application and economic returns [76]. However, the result is in contrast with the findings of [77], where fertilizer use was found to reduce the number of soil conservation practices adopted by farmers in Pakistan.

The extent of weeding is found to be positive and significantly related to the number of conservation practices adopted by farming households. Farmers who devote time for frequent weeding operations on their farms are 6.6% more likely to adopt two or more conservation practices. Frequent weeding operation of at least three times reduces nutrient competition caused by the presence of weeds such as *Striga hermonthica*, a major weed on maize fields in the study area. The amount of rainfall is positive and statistically significant in explaining the intensity of adoption of soil conservation practices by increasing the likelihood of adopting two or more practices by 33.1%. This supports the idea that rainfall is an important biophysical factor that explains farm management decisions and crop yields of farmers in rain-fed production systems, especially in developing country settings where there is limited use of irrigation. The result compares favorably with [15], where rainfall significantly increased the likelihood of adopting more than two soil conservation practices. Yet, it is not in line with the earlier empirical findings of [39] and [26], where the amount of rainfall was not significant in influencing the intensity of adoption of soil conservation practices.

We found that factors, such as age of farmer, the number of contacts with extension agents, adult equivalent household size, membership of association, farming experience, access to credit, number of maize fields, and ownership of mobile phones, were not significantly related to the intensity of adoption of soil conservation practices in our study area. This is consistent with some studies on adoption of conservation practices but not with other studies. [26] found that age of household head, access to credit, and membership of association, significantly influenced the intensity of adoption of soil conservation practices. [39] found out that access to credit and membership of association significantly influenced the intensity of adoption of soil conservation practices. Also, [77] found that the age of household head, household size, membership in association, access to extension, and access to credit significantly influence the intensity of adoption of soil conservation practices.

4. Conclusions

In this paper, we analyze the interdependence and temporal dynamics of smallholders' adoption of multiple soil conservation practices in northern Nigeria. We use two-period farm-household panel data from smallholder maize producing households, and estimate pooled multivariate probit and random effects ordered probit models. We found evidence of inter-temporal variability in the adoption of soil conservation practices, which suggests that some farmers do switch in and out of these practices and may likely explain variability in yields. In addition, the results indicate that the use of animal manure is more common in the study area, despite the observed inter-temporal variability. We found evidence of strong positive correlations among the soil conservation practices, which suggests complementarity among the practices adopted by farmers in the study area. The interrelationships among the conservation practices adopted may have important policy implications, in that a policy change that affects the adoption of one practice can have spill-over effects on the adoption of other practices. Such interrelationships can be leveraged for better design of appropriate packages of soil conservation practices and may in turn stimulate the adoption of the practices. Also, we found that the farmers' decision to adopt soil conservation practices and the intensity of adoption is influenced by several factors, including farmer-, household-, farm-, institutional- and biophysical-level factors. Yet, the factors that significantly influence the likelihood of adoption differ slightly from those that influence the intensity of adoption. In particular, the significant role of contract farming in driving

the intensity of adoption of conservation practices suggests that contract farming arrangement can be leveraged to enhance adoption intensity of conservation practices among smallholders. The vital role of livestock ownership in the adoption and adoption intensity of soil conservation practices necessitates policy interventions to encourage farmers involvement in crop–livestock integrated farming so as to increase the supply of manure. This can in turn allow of the use of manure to improve soil quality and crop yields. Also, the crucial role of access to income from off-farm sources on the decision to adopt and the intensity of adoption implies that policy measures to strengthen farmers participation in non-farm activities, particularly during off-season to generate additional income, may allow for increased investment in soil conservation practices.

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Appendix A

	2016 Cropping Season				2017 Cropping Season			
	Intercropping	Rotation	Manure	Residue	Intercropping	Rotation	Manure	Residue
$P(Y_k = 1)$	0.280	0.155	0.763	0.729	0.317	0.129	0.687	0.457
$P(Y_k = 1 Y_{IC} = 1)$	1	0.113 ***	0.775 ***	0.743 ***	1	0.040 ***	0.693 ***	0.494 ***
$P(Y_k = 1 Y_{CR} = 1)$	0.203	1	0.789 ***	0.650 ***	0.102	1	0.622 ***	0.388 ***
$P(Y_k = 1 Y_{MN} = 1)$	0.285***	0.161 ***	1	0.757	0.320 ***	0.112 ***	1	0.500 ***
$P(Y_k = 1 Y_{CSR} = 1)$	0.286***	0.139 ***	0.792 ***	1	0.343 ***	0.105 ***	0.751 ***	1
$P(Y_k = 1 Y_{IC} = 1 Y_{CR} = 1)$	1	1	0.800 ***	0.560 ***	1	1	0.800 ***	0.400 *
$P(Y_k = 1 Y_{IC} = 1 Y_{MN} = 1)$	1	0.116 *	1	0.738 ***	1	0.046 ***	1	0.506 ***
$P(Y_k = 1 Y_{IC} = 1 Y_{CRS} = 1)$	1	0.085 **	0.770 ***	1	1	0.032 *	0.710 ***	1
$P(Y_k = 1 Y_{CR} = 1 Y_{MN} = 1)$	0.206	1	1	0.680 ***	0.131	1	1	0.475 ***
$P(Y_k = 1 Y_{CR} = 1 Y_{CRS} = 1)$	0.175	1	0.825 ***	1	0.105	1	0.763 ***	1
$P(Y_k = 1 Y_{MN} = 1 Y_{CRS} = 1)$	0.278 ***	0.144 ***	1	1	0.324	0.107 ***	1	1
$P(Y_k = 1 Y_{CR} = 1 Y_{MN} = 1 Y_{CRS} = 1)$	0.167	1	1	1	0.138	1	1	1
$P(Y_k = 1 Y_{IC} = 1 Y_{MN} = 1 Y_{CRS} = 1)$	1	0.087	1	1	1	0.045	1	1
$P(Y_k = 1 Y_{IC} = 1 Y_{CR} = 1 Y_{CRS} = 1)$	1	1	0.786 ***	1	1	1	1 ***	1
$P(Y_k = 1 Y_{IC} = 1 Y_{CR} = 1 Y_{MN} = 1)$	1	1	1	0.550 ***	1	1	1	0.500

 Table A1. Unconditional and conditional adoption probabilities of soil conservation practices.

Y_k is a binary variable representing the adoption status with respect to soil conservation practice k (Intercropping (IC), Crop rotation (CR), Animal manure (MN), Crop residue retention (CRS)). *, ** and *** indicate statistical significance difference at 10%, 5% and 1% respectively. The comparison is between unconditional probability and conditional probability in each conservation practice.

Combination of Conservation Practices	2016 Cropping Season	2017 Cropping Season
	Percentage	Percentage
Animal manure + crop residue retention	57.7	34.52
Animal manure + crop rotation	12.25	7.74
Animal manure + intercropping	21.72	22.08
Crop residue retention + crop rotation	10.1	4.82
Crop residue retention + intercropping	20.83	15.74
Crop rotation + intercropping	3.16	1.27
Animal manure+ crop residue retention +crop rotation	8.33	3.68
Animal manure+ crop residue retention + intercropping	16.04	11.17
Animal manure+ crop rotation + intercropping	2.53	1.02
Crop rotation + intercropping+ crop residue retention	1.77	0.51
Animal manure + crop residue retention +Intercropping + crop rotation	1.39	0.51

Table A2.	Adoption i	intensity fo	r combination	of soil co	nservations	practices in	2016 and 2017	cropping sea	asons.

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