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Agricultural Extension Service and Technology Adoption for Food and Nutrition Security of Smallholder Farmers in Benue State, Nigeria

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The paper investigated the adoption decisions and the complementarities among four labor-intensive technologies and the comprehensive use of four modern inputs that have been frequently adopted by smallholder farmers in Benue State, Nigeria. The study also investigated whether the technologies that farm households adopted three and five years ago have effects on the food and nutrition security of the adopters. The study employed a multivariate probit model on a sample of 399 farm households in Benue State, Nigeria. It was found that all eight technologies that households adopted the technologies in previous years continued adopting the technologies in 2021, reflecting the profitability of agricultural technology adoption. More so, findings showed that there are statistically significant correlations among the eight technologies and between modern and labor-intensive technologies. The complementarities among the technologies imply that the (perceived) productivity of one technology depends on the adoption of another technology in that the farmers have to adopt the technologies together. For instance, the results indicated a strong complementarity between improved seed adoption and the three labor-intensive technologies including seeding in a row, (0.422), organic fertilizer use (0.137), and irrigation (0.084). The study found that the major determinants of adoption decisions of multiple technologies were the total value of crop harvest and livestock owned, experiencing natural shock, market shock, access to fertilizer credit, participation in meetings/trainings, distance to market, and timely access to inputs. In addition, it was found that the adoption of multiple technologies reduces food insecurity in households and increases dietary diversity. Specifically, the results revealed that the households who adopted improved seeds, chemicals, irrigation, organic fertilizer, extension service, and soil conservation mechanisms are less likely to experience food insecurity and are more likely to have higher household dietary diversity score (HDDS). In other words, the higher the number of technologies that the households adopted, the more likely that they are food secured and have a diversified diet. The study, therefore, concluded that agricultural extension services and technology adoption have a statistically significant and positive impact on food and nutrition security.

Keywords: Extension service, input complementarity, food and nutrition, agricultural technology adoption

INTRODUCTION

The prevalence of undernourishment is the highest in Africa where agriculture is the dominant sector and where there is a huge yield gap (Food and Agriculture Organization, 2017). According to Adewale (2002), despite the vast resources in Nigeria, food production has not kept pace with the increase in food demand as the agricultural sector has significantly underperformed its potential and this has been manifested in the high food prices, food insecurity both at household and national levels with attendance evidence in malnutrition especially among children. A review of food security and agricultural trends in the past 40 years in sub-Saharan Africa shows that achieving food security remains a challenging issue and food aid is still indispensable as many rural households in most developing countries remain disproportionally poor (de Graaff et. al., 2010). According to Green and Ng'ong'ola (1993), agricultural technology adoption is considered one means of securing food and nutrition by increasing productivity and rural income. The sustainability of agricultural development depends on the quality and effectiveness of extension services among other factors. Accordingly, Daneje et al. (2010) observed that there is a gap between agricultural performance and available research information in developing countries and this is due to poor agricultural extension services delivery and limited interaction between researchers and development agents (DAs).

To achieve agricultural deployment and ensure food security, the challenges are therefore to find ways of encouraging farmers to use improved farm technologies through an extension system that would reach the farmers promptly and effectively. Several studies empirically investigated the adoption decisions and the contribution of agricultural technologies to improving the income of smallholder farmers. For instance, in Tanzania, Magrini and Vigani (2016) found among maize that the adoption of improved seed and inorganic fertilizers increased the availability of food. Similarly, in Ethiopia, Jaleta et al. (2015) found that adoption of improved maize varieties increases consumption per capita. In India, Mahanta and Rai (2008) found that inorganic fertilizer increases productivity and is profitable in soybean and wheat production. More so, in Uganda, Pan et al. (2015) found that the adoption of agricultural extension services that focused on improving the cultivation method increased agricultural production, savings, and wage income. In Nigeria, Ogebe and Adanu (2018) found that the adoption of agricultural extension services that focused on the adoption of improved maize and sorghum varieties increased maize and sorghum outputs and incomes of cereal farmers in the Kaduna State of Nigeria. However, most of these studies analyzed the adoption decisions for a single technology or joint adoption of only a few of the many technologies that farmers practically use.

Emerging studies found that studies based on single or only a few joint technologies adoption decisions suffer from endogeneity and simultaneity problems and provide an incomplete picture of the reality since practically farmers choose among and use multiple technologies (Abate et al., 2016). More so, previous studies that investigated the effects of technologies on the welfare of farmers do not control for the dynamic effects of income and technology adoptions. Studies that do not address the dynamic effect of wealth on food and nutrition security may suffer methodological flaws resulting in inaccurate estimates. This paper aims to contribute to this literature gap. This research, therefore, investigates the impact of agricultural extension services and technology adoption on the food and nutrition security of smallholder farmers in Nigeria. Specifically, the study examines the technology adoption rates and trends among adoption of technologies over the survey periods, investigates correlations among agricultural technologies, ascertains the number of technologies adopted by households, assesses food and nutrition security of the households, ascertains determinants of adoption decisions of multiple technologies and estimates the effects of technology adoption on food and nutrition security of the households in the study area.

MATERIALS AND METHODS

The study area

The study area was Benue State, located in the middle belt of Nigeria. The State is second on the list of highest rice producing States in the country, producing a capacity of 1,500,000 MT per year (Nigerian Infopedia, 2022). Its geographic coordinates are longitudes 6^0 35 and 10^0 0E, and latitudes 6^0 30 and 8^0 10N with a population of 5,741,800 people with 413,159 farm families/households (National Population

Commission, 2007). The State shares boundaries with five other States namely; Nasarawa State to the North, Taraba State to the East, Cross Rivers to the South, Enugu to the South-West, and Kogi to the West. The State also shares a common boundary with the Republic of Cameroun to the South-East, and it occupies a total landmass of 32,518km^2. Benue State has a tropical sub-humid climate, with two distinct seasons which are the wet season and dry season. The wet season lasts for seven months and is between April and October with annual rainfall ranging from 1500 – 1800 mm. The dry season comes between November and March. Temperatures are generally very high during the day with average daily temperatures ranging between 21^0 – 35^0 C in the summer and 16^{0}C – 37^{0}C in the winter. Most of the people are farmers while the inhabitants of the riverine areas engage in fishing as their primary occupation. About 80% of the population is estimated to earn their living from agricultural production Benue Agricultural and Rural Development Authority (BNARDA, 2004). The State is the major producer of food crops such as yam, cassava, sorghum, and maize. The major cash crops include rice, soybeans, and beniseeds. Citrus, sugar cane, oil palm, and banana are other economic crops grown in the State. Livestock rearing such as cattle, sheep, goats, pigs, and poultry are also practiced in the State, hence the name, 'Food Basket of the Nation'.

Sampling Procedure

The secondary data were obtained from Benue Agricultural and Rural Development Authority (BNARDA, 2017). A multi-stage sampling method was used in the selection of respondents. The first stage was a selection of two (2) Local Government Areas (LGAs) from each of the three (3) agricultural zones in Benue State purposively due to the high concentration of food production in these zones, making a total of six (6) LGAs. Enumeration areas (EAs) were also randomly selected from LGAs. The sampling frame of households was generated using the 2006 census enumeration list. The final stage was a simple random proportionate sampling of 399 household heads from a sample frame of 24, 6172 respondents from six (6) LGAs in the state using Taro Yamane's formula at 5% precision. Taro Yamane's formula is stated as:

$$n = \frac{N}{1+N(e)2} \qquad \text{...... equ.(1)}$$

Where;
n= the sample size
N= the population under study
e= the level of precision
1 = unity of constant

Primary data such as information on the socio-economic characteristics of households, market existence, households' access to credit, and other demographic information were collected using a well-structured questionnaire.

Data analysis

The study employed the multivariate probit model to analyze multiple technology adoption decisions of the farmers. A household, i adopts a technology, K (where K Є {DA visit, soil conservation practice, irrigation, seeding in a row, improved seed, inorganic fertilizer, organic fertilizer, chemicals), at the time, t, if the expected net benefit of adoption, yk* is positive. That is,

$$y_{ik}\begin{pmatrix} 1\ if\ y*itk > 0 \\ \\ 0\ if\ y*itk < 0 \end{pmatrix} \qquad \text{.......equ(2)}$$

The expected net benefit, y*ik, is a latent (unobserved) variable that is determined by observable variables and unobserved factors, and given by:

	1	p_{12}	p_{13}	p_{14}	p_{15}	p_{16}	p_{17}	p_{18}		
	p_{21}	.						.		
	p_{31}		.					.		
'Ω=									.	...equ(4)
	.			.	.			.		
	.					.	.	.		
	p_{81}	.	.	.	.	.	.	1		

y^*itk = αi +yihβ +Xiδ +εikt, K= 1, 2, ...8 ....equ (3)

Where αi is the time-invariant household-specific latent variable that is assumed to be common across the eight adoption decisions. These unobserved time-variant variables may include agroecological factors, behavioral factors, and plot characteristics. yih is a sector of lagged covariates including past adoption decisions. Xit is a vector of exogenous covariates. The εikt is an error term, which is assumed to be identically and independently distributed, but the εikt is allowed to correlate across the eight equations. The error term jointly follows a multivariate normal distribution with zero conditional means, variance normalized to unity (for identification), and a symmetric covariance given by:

A key issue in the multiple agricultural technologies' adoption decision is that the adoption decision of technology correlates with the adoption of the decision of other technologies. That is, the net benefit of adopting a technology depends on the net benefit of adopting other technologies. Thus, the probability of adopting technologies could be correlated, in that the off-diagonal coefficients in equation 4 will be statistically different from zero. The computation of the estimation of adoption decisions involves an eight-dimensional integration problem. The integrals are evaluated using the Maximum Simulation Likelihood approach, where the Geweks-Hajivassilious-Keane GHK) smooth recursive conditioning simulator is useful for efficiency gain. Ordered probit model was used for the estimation of the number of months that the household experienced food shortage problems in the 12 months preceding the survey since the dependent variable is an ordered count variable. Ordered probit model is specified as:

$$\text{Pr.}\quad (y_i=J) = \begin{pmatrix} J\ if\ y*<0 \\ J+1if\ 0<y*i<\mu i, \\ j+n \end{pmatrix}$$

…….equ.(5)

y*= αi +yisβ +Xiδ +εi,

Where j=1 and n=12 represent the 12 months in a year that the household experienced a food shortage problem, yi* is the unobserved food security status of household I, yis is a vector of past years values of the dependent variable for household i, X is a vector of exogenous covariates, αi, and δ are vectors of population parameters of interest to be estimated and εi is a standard normally distributed error term independent of the covariates. The instrumental variable general method of moments (GMM) framework of the Poisson model was used to estimate the effects of adoption on HDDS. The instrumental variable approach was used to control for the endogeneity problem between HDDS and production diversity arising from inseparable production and consumption decisions.

Mathematically, the model is specified as:

HDDSi =esp (HDDS$_{is}$θ + Xir +IV (PD) + εi …..equ.(6)

Where IV is HDDSi is the DD score of household in 2021, HDD$_{is}$ is the DD score of the household i in 2015 and 2017, X denotes a vector of exogenous covariates affecting HDDS, IV (PD) denotes the estimated values from first stage estimation of production diversity using instruments including cultivated land size and weather indicator variables, and εi is the error term independent of covariates. The probit model was used for the estimation of the dummy variables of whether the households experienced food shortage in the dry season and if the household ate only a few varieties of food due to income constraints to buy more varieties.

$$Y_{itk} = \begin{pmatrix} 1\ if\ yitk*>0 \\ \\ 0\ if\ yitk*<0 \end{pmatrix} \qquad \text{……. equ.(7)}$$

yi* = αi +y$_{is}$β +X$_{ih}$δ +εi,

Where yi* denotes the two binary dependent variables regressed independently for household i, y$_{is}$ a vector of past years, s, values of the dependent variables, X is a vector of the exogenous covariates, α, β, and δ are vectors of population parameters of interest to be estimated and εi, is a standard normally distributed error term independent of the covariates.

RESULTS AND DISCUSSION

Technology Adoption Rates and Trends among Adoption of Technologies over the Survey Periods

Table 1 presents the adoption rates of eight agricultural technologies in the study area. The percentage of households who used DA service in the 12 months preceding the surveys was 50% in 2015, 55% in 2017, and 53% in 2021; whereas the percent of households who practiced soil conservation in the five years preceding the surveys was around 75% in 2015, 63% in 2017 and 68% in 2021. The share of the households who irrigated their land was below 15% in all survey years while about half of the households planted the seeds in a row in

Table 1. Technology Adoption Rates and Trends among Adoption of Technologies over the Survey Periods.

Technology types	N	2015 (%)	2017 (%)			2021 (%)		
			Continued adopting	New adopters	Total	Continued adopting	New adopters	Total
Households received DA service	399	50	35	20	**55**	44	9	**53**
Households adopted improved seeds	399	26	18	11	**29**	22	21	**43**
Households adopted chemicals	394	48	22	12	**34**	36	14	**50**
Households adopted fertilizer	399	62	47	15	**62**	58	11	**69**
Households adopted soil conservation	390	75	50	13	**63**	57	11	**68**
A household planted a seed in a row	399	55	40	16	**56**	49	13	**62**
Households irrigated part/all of plot (s)	399	15	5	4	**9**	10	6	**16**
Households adopted organic fertilizer	399	75	18	6	**24**	43	10	**53**

Source: Author's Computation, 2022.

all three survey years. While the adoption of some technologies such as improved seed, DA service, and inorganic fertilizer increased over time, the adoption of soil conservation and irrigation declined. The observed lower adoption of soil conservation practices in 2017 and 2021 could be that once adopted in 2015, most of the soil conservations last a long time in that the farmers may not need to adopt the technology again on the same plot the five years of the survey period.

Furthermore, the results in Table 1 showed that more than half of the households who adopted the technologies in 2015 continued adopting the technology in 2017. For instance, 35% of the households that used the DA service in 2015 also used it in 2017 while 20% of households that did not use the DA service in 2015 used it in 2017. Similarly, more than half of the households who adopted the technologies in 2015 or 2017 continued using the technologies in 2021. For instance, 58% of households who adopted improved in 2015 or 2017 also adopted in 2021 while only 13% of the households who did not adopt improved seeds in 2015 and 2017 adopted the technology in 2021.

Correlations among Agricultural Technologies in the Study Area

Table 2 presents the correlations among eight agricultural technologies. The results showed that there are statistically significant correlations among the eight technologies and between modern and labor-intensive technologies. The complementarities among the technologies imply that the (perceived) productivity of one technology depends on the adoption of another technology in that the farmers have to adopt the technologies together.

Number of technologies Adopted by Households over the survey period

Table 3 showed that most of the households have been adopting more than one technology in each of the survey years, indicating that single input adoption

Table 2. Correlation among Adoption of Technologies over the Survey Periods.

Technology types	2015	2017	2021
Correlation between seeds in a row and:			
DA advises	0.0771***	0.1481***	0.1701***
Soil conservation	0.0007NS	0.0134NS	-0.0271**
Improved seed	0.3225***	0.3287***	0.3632***
Irrigation	0.1071***	0.0838***	0.0710***
Chemicals	0.1427***	0.0525***	0.0522***
Inorganic fertilizer	0.2614***	0.1872***	0.2967***
Organic fertilizer	0.1467***	0.1083***	0.0971***
***Correlation between DA visit and**:*			
Soil conservation	0.1532***	0.1547***	0.1815***
Improved seed	0.2476***	0.2271***	0.2250***
Irrigation	0.0734***	0.0758***	0.0514***
Chemicals	0.0276**	0.1277***	0.0561***
Inorganic fertilizer	0.2426***	0.3138***	0.3827***
Organic fertilizer	0.0869***	0.0867***	0.1605***
Correlation between improved seed adoption and:			
Soil conservation	0.1246***	0.1076***	0.0617***
Irrigation	0.0882***	0.1168***	0.0378***
Chemicals	0.1214***	0.0733***	0.1134***
Inorganic fertilizer	0.3853***	0.3474***	0.3097***
Organic fertilizer	0.0732***	0.1014***	0.0822***
Correlation between irrigation Use and:			
Chemicals	0.0368***	0.0014NS	0.017NS
Soil conservation	0.1238***	0.0881***	0.0572***
Inorganic fertilizer	0.1233***	0.1055***	0.1030***
Organic fertilizer	0.0282**	0.0627***	0.0322***
Correlation between chemical Use and:			
Inorganic fertilizer	0.3267***	0.3210***	0.2126***
Soil conservation	0.0778***	0.1129***	0.0852***
Organic fertilizer	0.0864***	0.0273**	0.0567***
Correlation between organic and inorganic fertilizer adoption:	0.1319**	0.0585***	0.1138***
Correlation between soil conservation and inorganic fertilizer	0.2279***	0.2172***	0.2149***
Correlation between soil conservation and organic fertilizer	0.0717***	0.0466***	0.0748***

Notes: *, **, and *** respectively indicate that the pairwise correlations are statistically significant at <10%, <5%, and < 1% levels of significance. Source: Author's Computation, 2022.

decision analysis could be inaccurate. The results showed that around 3%, 8%, and 9% did not adopt any of the eight technologies in 2015, 2017 and 2021, respectively. On the other hand, 0.88%, 0.26%, and 0.62% of the households adopted all eight technologies in 2015, 2017, and 2021 respectively. The rest of the households adopted two to seven technologies at a time. In general, Table 3 shows that 80% of the households adopted at least two technologies in 2021.

Food and Nutrition Security of Households in the Study Area

Two indicators of food and nutrition security were used to measure the food security conditions of the households. The first measure is the number of months that households experienced food shortage problems in the 12 months preceding the survey. This measure could show the year-long food security condition of the households. The second indicator is the household dietary diversity score (HDDS) which consists of 10 food groups where households were asked if any of the household members consumed the mentioned food groups in the seven days preceding the survey. Table 4 presents the number of months and the corresponding percentage of households that were food insecure within a year. The percentage of households who reported that they were not food insecure increased from 47% in 2015 to 75% in 2021. On the other hand, the percentage of households who reported that they were food insecure throughout the year increased from 0.84% in 2015 to 1.07% in 2021. The rest of the households reported between one to eleven months of food insecurity. Table 5 presents the results of the HDDS under each of the ten scores (food groups).

Adoption Decisions of Multiple Technologies

Table 6 presents the regression results from the multivariate probit model of adoption decisions and the complementarities among labor-intensive technologies and the use of modern inputs. Most of the estimates for each of the equations have the expected sign and are jointly statistically significant, indicating that there are indeed complementarities among the adoption of the technologies. The results showed that there was strong complementarity between improved seed adoption and the three labor-intensive technologies including seeding in a row (0.422), organic fertilizer use (0.137), and irrigation (0.084). The results also showed input complementarity between the DA visit and all four labor-intensive technologies and between the adoption of conventional fertilizer and labor-intensive technologies, except with organic fertilizer expectedly. The complementarities may indicate that the adoption of modern inputs induces farmers to adopt labor-intensive technologies to increase the productivity of modern inputs and, thereby to pay for the input costs. Results indicated that extension service (DA visit) has a statistically significant complementarity with improved seed (0.306) and inorganic fertilizer adoption (0.221) as well as labor-intensive and sustainable technologies including irrigation (0.071), soil conservation (0.072), seeding in a row (0.073) and with organic fertilizer adoption (0.059). However, the degree of complementarities between Das visit and sustainable technologies is weaker than the degree of complementarities between DAs visit and modern inputs, perhaps indicating that farmers do not much need the consultation of DAs to implement sustainable and labor-intensive technologies as most of these technologies are well known among farmers. Moreover, the relatively weaker between DAs visit and labor-intensive technologies may also indicate that the Das visit primarily aims at consulting farmers to adopt modern inputs.

Strong complementarity exists between inorganic fertilizers and improved seed adoption (0.45). The study found that farmers who adopted technologies once are more likely to adopt the technologies again as it was found that all eight technologies that households who adopted the technologies in previous years (2015 and 2017) continued adopting the technologies in 2021). This is consistent with Besley and Case (1993) who found that once farmers choose to use technologies, they are most likely to continue using the technologies, perhaps due to learning behavior about the net benefits of the technologies. It was found that past extension services have statistically significant effects on improved seed adoption, soil conservation, and organic fertilizer use. However, past extension service has a statistically significant negative effect on the adoption of irrigation. Effects of other covariates on the adoption propensity showed that households headed by mature persons are more likely to seek extension service, plant the seeds in a row, and adopt improved seeds, and inorganic and

Table 3. Number of Technologies Adopted by Households in the Study Area.

No. of Technologies Adopted	Percentage Households		
	2015	**2017**	**2021**
0	2.55	7.40	8.82
1	12.92	18.62	13.06
2	15.12	16.94	14.27
3	16.66	20.66	15.66
4	17.75	17.25	17.42
5	15.99	13.14	14.89
6	12.39	4.22	11.22
7	5.74	1.51	4.04
8	0.88	0.26	0.62
N	**399**	**399**	**399**

Source: Author's Computation, 2022

Table 4. Number of Months with Food Insecurity during the Last 12 Months, over the Survey years.

No. of months with food insecurity problem	Percentage Households		
	2015	**2017**	**2021**
0 (Food secure)	47.29	32.62	74.82
1	8.24	43.54	3.66
2	17.41	17.61	8.56
3	13.00	3.23	5.01
4	5.12	1.04	2.07
5	3.22	0.66	1.58
6	2.41	0.47	1.66
7	0.92	0.13	0.24
8	0.53	0.22	0.71
9	0.38	0.02	0.10
10	0.51	0.11	0.48
11	0.13	0.09	0.04
12	0.84	0.26	1.07

Source: Author's Computation, 2022

organic fertilizers. Adoption propensity of most technologies increases with the percentage increase in the value of total crop harvest and the value of livestock owned, possibly because relatively rich households can afford to buy the technologies and the inputs used to adopt the technologies, are risk averse and perhaps reflecting economies of scale. The results showed that experiencing natural shocks such as drought, flooding, and storm, and market shocks such as input price inflation or output price deflation negatively affect the propensities of adoption. Furthermore, access to fertilizer credit,

Table 5. Household Dietary Diversity Score

No. of food groups consumed during the last 7 days, HDDS	Percentage Households		
	2015	2017	2021
Only one	0.55	3.10	1.08
Two	3.94	7.31	4.52
Three	12.22	16.05	14.88
Four	19.21	22.18	22.94
Five	26.82	22.21	28.77
Six	21.51	15.86	16.59
Seven	12.57	7.56	7.00
Eight	2.51	3.88	3.33
Nine	0.52	1.60	0.66
Ten	0.15	0.25	0.23
Mean	**5.02**	**4.64**	**4.72**

Source: Author's Computation, 2022.

participation in community training and meetings, distance to the market, and timely access to the inputs affect the propensity of adoption of most of the eight technologies. The study found that households substituted the adoption of chemicals by hiring labor for weeding.

The Effects of Technology Adoption on Food and Nutrition Security

The results in Table 7 showed that there is a strong tenacity in food and nutrition insecurity, perhaps indicating the cycle of poverty with the implication of the need for intervention to break the cycle. The results showed that households who were food insecure in 2015 and/or 2017 are more likely to be food insecure in 2021. The number of months with food security problems is higher in 2021 for households who experienced longer months with food security in 2015/2017. Households that had diverse diets in 2017 have also diverse diets in 2021. More so, the household dietary diversity score is higher in 2021 for households who had a higher HDDS in 2015. The results revealed that the higher the number of technologies that the households adopted, the less likely that they experience food shortage problems and the higher the HDDS of the households. This implies that the adoption of complementary technologies is essential to increase agricultural productivity and thereby secure food. Furthermore, the results indicated that households who adopted improved seeds in 2015 are less likely to experience food shortage problems and lower the number of months that they experience food shortage problems in 2021. This is because improved seeds increase agricultural productivity and thereby improve food security (Emerick et al., 2016). Similarly, households who adopted organic and conventional fertilizers, irrigation, and soil conservation mechanisms are less likely to experience food insecurity and are more likely to have higher HDDS. Also, households who adopt chemicals are more likely to have a higher HDDS, perhaps because chemicals increase agricultural production and productivity despite the negative externalities on health, environment, and o sustainability. The results further showed that households with better economic standing measured by the total value of agricultural production and landholding are more likely to be food secure. Households who follow price information are more likely to be better off in terms of the two indicators of food and nutrition security perhaps indicating that information access is one of the key factors that farmers need to improve their living standards.

On the contrary, the results showed that

Table 6. Multivariate Probit Estimates of Joint Technology Adoption Decisions.

Covariates	Adopted Technology Type							
	Extension service	Seeding in a row	Soil conservation	Irrigation	Improved seed	Chemicals	Organic fertilizer	Inorganic fertilizer
Constant	1.8110*** ((-8.36)	1.811*** (-7.88)	-8.8001** (-3.61)	2.8801*** (-9.05)	4.4211*** (-17.10)	2.5450*** (6.30)	4.008*** (-14.53)	0.0564 (0.30)
Past adoption decisions								
Adoption in 2017	0.2611*** (7.31)	0.687*** (17.69)	0.3711*** (9.00)	1.138*** (15.10)	0.4790*** (11.62)	0.06131 (0.89)	0.719*** (15.06)	0.341*** (8.77)
Adoption in 2015	0.431*** (11.64)	0.811*** (20.79)	0.417*** (10.44)	0.787*** (11.89)	0.6323*** (15.48)	0.2740*** (3.84)	0.752*** (16.44)	0.397*** (10.29)
Extension service in 2017	0.261*** (7.26)	0.0678 (1.56)	0.0568 (1.70)	-0.127* (-2.40)	0.0867* (2.06)	-0.0067 (-0.10)	-0.0230 (-0.68)	0.0711 (1.78)
Household characteristics								
Male HH head	0.0614 (1.07)	-0.151* (-2.28)	0.3001*** (4.71)	0.224* (2.38)	-0.0214 (-0.36)	0.0312 (0.26)	-0.0726 (-1.16)	0.0478 (0.77)
Mature HH head	0.156** (3.72)	0.127** (2.88)	-0.0209 (-0.48)	0.0672 (1.16)	0.0867* (2.11)	-0.0634 (-0.81)	0.124* (2.48)	0.22*** (5.38)
Literate HH head	-0.0261 (-0.53)	-0.110* (-2.70)	0.115* (2.58)	-0.0875 (-1.77)	-0.110* (-2.49)	0.0534 (0.82)	-0.20*** (-3.88)	-0.003 (-0.06)
Cultivation area (ha)	-0.0028 (-0.19)	-0.0125 (-0.88)	-0.0617*** (-4.78)	-0.0155 (-0.81)	-0.0117 (-0.89)	0.0408 (1.55)	-0.0138 (-0.72)	-0.0118 (-0.86)
The total value of crops and livestock (log)	0.106*** (5.26)	0.136*** (6.10)	0.120*** (5.46)	0.119** (3.67)	0.312*** (13.04)	-0.122* (-2.74)	0.331*** (12.37)	-0.0002 (-0.01)
Shocks experienced								
Natural shock	0.121* (3.30)	-0.078* (-2.09)	0.118* (2.82)	-0.0135 (-0.27)	0.0218 (0.54)	-0.0146 (-0.21)	0.0271 (0.56)	0.190*** (5.05)
Market shock	-0.179*** (-4.31)	0.078* (2.30)	-0.0254 (-0.63)	-0.0087 (-0.18)	-0.256* (-1.20)	0.258* (3.17)	0.189** (3.89)	0.18*** (4.63)
Information and market access								
Had credit access to fertilizer					2.81*** (6.74)	-0.230* (-3.16)	1.018*** (16.61)	0.0816 (1.87)
Follow price information	-0.0588 (-0.88)	-0.0515 (-0.66)	0.220* (2.36)	0.131 (1.20)	-0.0852 (-0.81)	-0.0138 (-0.07)	-0.144 (-1.52)	0.0509 (0.74)
Participate in meetings/training	0.586*** (15.67)	0.199*** (4.68)	0.274*** (6.27)	0.187* (3.17)	0.0717 (1.69)	0.0677 (1.09)	0.153* (3.22)	0.0839* (2.19)
Have media access	0.0899 (1.17)	0.00560 (0.07)	-0.155 (-1.72)	-0.0782 (-0.77)	0.0677 (0.70)	0.155 (1.02)	0.0899 (0.01)	-0.0415 (-0.56)
Distance to the nearest market	-0.00035 (-1.75)	-0.001 (-5.62)	-0.0008 (-2.67)	-0.00009 (-2.23)	-0.001*** (-4.17)	0.00068 (1.76)	-0.001** (-6.85)	-0.00006 (-0.20)
Timely access to the input					0.741*** (18.38)	0.0997 (1.18)	0.857*** (19.67)	

Table 6. Continue.

Hired-in labor for weeding						-0.0008* (-2.47)		
Correlations (complementarities)								
p_{21}(DA visit & row seeding)			0.0642* (2.88)	ρ_{43} (Soil conservation & irrigation				0.2300** (5.48)
p_{31}(DA visit & soil conservation)			0.0818* (2.72)	ρ_{53}(soil conservation & improved seed)				0.0437 (1.62)
p_{41} (DA visit & irrigation)			0.0608* (2.04)	ρ_{63}(soil conservation & chemicals)				-0.0226 (-1.21)
p_{51}(DA visit & improved seed)			0.3091*** (11.32)	ρ_{73}(soil conservation & conventional fertilizer)				0.1132** (3.81)
p_{61} (DA visit & chemicals)			-0.0311 (-1.20)	ρ_{83}(soil conservation & organic fertilizer)				0.0861* (3.64)
p_{71}(DA visit &conventional fertilizer)			0.2230*** (7.48)	ρ_{54}(irrigation & improved seed)				0.0800* (2.39)
p_{81}(DA visit & organic fertilizer)			0.0586* (2.38)	ρ_{64}(irrigation & chemicals)				0.0311 (0.77)
p_{32} (Row seeding & soil conservation)			-0.0016 (-0.04)	ρ_{74}(irrigation & conventional fertilizer)				0.0843* (2.16)
p_{42}(Row seeding & irrigation)			0.1731*** (4.78)	ρ_{84}(irrigation & organic fertilizer)				0.0715* (2.10)
p_{52}(Row seeding & improved seed)			0.4220*** (13.86)	ρ_{65}(chemicals & improved seed)				0.269*** (9.24)
p_{62}(Row seeding & chemicals)			0.1771*** (6.77)	ρ_{75}(chemicals & conventional fertilizer)				0.778*** (21.29)
p_{72}(Row seeding & conv. fertilizer)			0.3610*** (11.74)	ρ_{85}(chemicals & organic fertilizer)				-0.0258 (-1.00)
p_{82}(Row seeding & organic fertilizer)			0.1441*** (5.88)	ρ_{76}(improved seed & conventional fertilizer)				0.461*** (14.13)
p_{86}(Improved seed &organic fertilizer)			0.1370*** (5.16)	ρ_{87}(conventional & org. fertilizer)				0.0270 (0.81)

Source: Author's Computation, 2022 t statistics in parentheses. *$p<0.05$, **$p<0.001$ and ***$p<0.0001$

households who planted the seed in a row are more likely to be food insecure and less likely to have dietary diversity, perhaps indicating that seeding in a row may not be a profitable technology because of the high labor-hour it demands. Another unexpected result is that households who were visited by Das in 2017 are more likely to experience more months of food insecurity. The possible explanation is that once a household receives DA service the previous year, the time that a farmer wastes attending training and visiting demonstration plots could negatively impact food security. Moreover, the results showed that, while households who hired in labor are more likely to have higher HDDS, households who hired out family labor are more likely to experience food shortages. This could be because while farmers who

Table 7. The Effects of Technology Adoption on Food and Nutrition Security.

Covariates	Dynamic Ordered Probit Model	GMM IV Poisson
	Months of food shortage problem	HDDS
Constant		0.1290 (0.68)
Dynamic (Past food security)		
Food security in 2017	0.0486* (2.38)	0.0243*** (5.01)
Food security in 2015	0.0382** (3.28)	0.0072 (1.13)
Technologies effect		
Number of technologies adopted	-0.0217 (-1.30)	0.0149* (2.67)
Adopted improved seed in 2017	-0.2070* (-3.18)	-0.0471 (-1.98)
Adopted improved seed in 2015	-0.1300* (-1.88)	-0.0241 (-1.31)
Adopted conventional fertilizer in 2017	0.0714 (1.40)	-0.0055 (-0.33)
Adopted conventional fertilizer in 2015	-0.0516 (0.85)	0.0570* (2.39)
Adopted chemicals in 2017	-0.0634 (-1.09)	0.0256 (1.70)
Adopted chemicals in 2015	0.0428 (0.81)	0.0311 (1.88)
Adopted DA in 2017	0.0811 (1.76)	-0.0211 (-1.30)
Adopted DA in 2015	-0.1080* (-1.88)	0.0062 (0.41)
Adopted irrigation in 2017	0.0744 (0.60)	0.0268 (0.91)
Adopted irrigation in 2015	-1.1011 (-1.05)	0.0450 (1.82)
Adopted organic fertilizer in 2017	-0.0677 (-1.32)	0.0328 (1.77)
Adopted organic fertilizer in 2015	0.0345 (0.64)	-0.0456 (-2.58)
Adopted soil conservation practice in 2017	-0.1580** (-3.30)	-0.0139 (-1.00)
Adopted soil conservation practice in 2015	-0.1391 (-2.45)	-0.0133 (-0.51)
Planted seed in a row in 2017	0.1720* (2.88)	-0.0339 (-1.67)
Planted seed in a row in 2015	0.01785(0.32)	-0.0741* (-2.83)
Wealth status		
The cultivated area in hectare	-0.0900** (-3.77)	0.0371** (3.64)
The total value of production in 2000, log	-0.2290*** (-9.11)	0.1290*** (8.49)
Information and market access		
Agricultural revenue, log		-0.0021 (-0.48)
Have media access	-0.0761 (-1.05)	0.0421 (1.56)
Follow price information	-0.2370** (-3.79)	0.0491 (1.48)
Hired in labor in 2017	0.0817 (1.28)	-0.0052 (-0.16)
Hired in labor in 2015	-0.0367 (-0.37)	0.0295 (1.74)
Hired out family labor in 2017	0.0787 (1.18)	0.0316 (1.66)
Shock variables, community participation		

Table 7. Continue.

Experienced natural shock in 2017	0.3310*** (0.74)	-0.0324 (-1.38)
Experienced natural shock in 2015	-0.1223 (-1.09)	-0.0138 (-0.56)
Sick or dead spouse	0.2871*** (5.58)	0.0032 (0.19)
Participated in meetings/trainings in 2015	0.1780** (3.70)	0.0529* (3.25)
Production diversity		0.0288*
Household characteristics	Yes	Yes
Log-likelihood	-3511.4613	

Source: Author's Computation, 2022. t statistics in parentheses. * $p<0.05$, ** $p< 0.001$, *** $p< 0.0001$

hired labor increase their agricultural production, poor farmers hired out family labor to curtail their short-run food shortage problem at the expense of less labor time than the required amount allotted to own production. The study revealed that farmers who experience natural shocks such as drought and flood as well as the death or illness of a spouse are more likely to be food insecure.

CONCLUSION AND POLICY RECOMMENDATION

The study investigates whether the technologies that farm households adopted three and five years ago have effects on the food and nutrition security of their households. The study measures food and nutrition security using two variables including the number of months households experienced food shortage during the last two months and household dietary diversity score (HDDS). Using a multivariate probit model on a sample of 399 households in Benue State, Nigeria, the study analyzed the adoption decisions of a comprehensive eight modern inputs and labor-intensive technologies including improved seed varieties, inorganic and organic fertilizers, chemicals, extension service, irrigation, soil conservation practices and planting seeds in a row. Finally, the study analyzed the determinants of the adoption of the eight technologies and found that adoption of the technologies reduces food insecurity and increases dietary diversity. Specifically, the study found that the higher the number of technologies that the households adopted, the more likely that they are food secure and have a diversified diet. This has an interesting policy implication that policies should aim at encouraging multiple technologies adoption by providing credit for the rural poor who cannot afford joint adoption of multiple technologies.

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