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Gendered Analysis of the Economic Impact of Adoption of Multiple Climate-Smart Agriculture Practices in Nigeria

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Abstract

Climate change significantly threatens Nigeria's food security and agricultural livelihoods. This study estimated the economic impact of the adoption of multiple climate-smart agriculture (CSA) practices in Nigeria through a gender lens and evaluated the impact on farmers' net income. Data for the study was sourced from the Nigeria Generalized Household Survey Panel data collected from 2011 to 2016. A two-stage endogenous switching regression model was used to analyse CSA adoption and farm income data. The findings reveal widespread adoption of diverse CSA packages, with mixed cropping and improved seed use being the most common (23.52%). The study established a positive association between CSA adoption and net farm income, adopting four CSA practices ($I_0M_1V_1F_1O_1$) increased the farmers' income gain to 9,743.90 thousand Naira per hectare. However, a concerning gender gap emerged, adopting a combination of $I_0M_1V_1F_1O_1$ saw a net income gain of 32,617.74 thousand Naira per hectare for the male farmers, while females saw a loss of 42.153 thousand Naira per hectare in adopting same, indicating a gender gap in economic benefits. This disparity highlights the need for interventions that address gender inequality in resource access and decision-making power.

Keywords: *Climate-Smart Agriculture, Gender Disparities Economic Impact, Crop Farmers*

Introduction

Agriculture is a cornerstone of Nigeria's economy, contributing significantly to employment, food security, and income generation (Apeh et al., 2023a; Chiemela et al., 2022). The sector employs about 70% of the labour force and contributes approximately 27% to the country's Gross Domestic Product (GDP) (National Bureau of Statistics (NBS), 2022). Despite its critical role, Nigerian agriculture faces significant challenges, including low productivity, inadequate infrastructure, and vulnerability to climate change (Agboola et al., 2024; Apeh et al., 2024; Ugwuoti et al., 2023). Climate change poses a severe threat to agricultural productivity in Nigeria, manifesting through irregular rainfall patterns, increased temperatures, and more frequent extreme weather events (Apeh et al., 2024; Tshikororo et al., 2024; Ugwuoti et al., 2023). These changes exacerbate existing vulnerabilities and threaten the livelihoods of millions of farmers (Apeh et al., 2023b; Apeh et al., 2024). To address these challenges, the adoption of Climate-Smart Agriculture (CSA) practices has become essential.

Climate-smart agriculture is an approach that seeks to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate (Wakweya, 2023). CSA aims to achieve three main objectives: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions where possible (Cordovil et al., 2020). Several studies have documented the positive impact of adopting new agricultural practices on farm income (Alemayehu et al., 2024; Chukwuone et al., 2021). Beyond single-practice adoption, research also suggests benefits from broader agricultural approaches. Sardar et al. (2020) observed a substantial increase in farm revenue (over 48%) for farmers who embraced various CSA techniques compared to those who did not. Teka and Lee (2020) further supported this notion, finding that Ethiopian farmers who implemented different CSA combinations experienced income growth over three years. Workineh et al. (2020) echoed these findings, demonstrating that the adoption of improved maize and wheat varieties in Ethiopia had a positive and significant impact on farm household income. Therefore, these studies collectively highlight the significant potential for increased farm earnings through the implementation of improved agricultural practices, including both specific technologies like genetically modified seeds and broader approaches like Conservation Agriculture.

Nigeria's agricultural sector, vital for its economy and food security, faces mounting challenges due to climate change (Apeh et al., 2023a; Ohagwu et al., 2024; Tikon et al., 2023; Ugwuoti et al., 2023). Climate-smart agriculture practices emerge as a promising solution for sustainable food production and climate resilience (Apeh et al., 2024; Gabriel et al., 2023). However, existing research often focuses on single practices or neglects gender dynamics in adoption.

This study addresses two key gaps in the literature. First, while several studies explored single CSA practice adoption (Alemayehu et al., 2024; Salisu, 2022), farmers often adopt a combination of practices for synergistic benefits (Chukwuone et al., 2021). This research investigated how gender inequalities in resource access and decision-making power can influence CSA adoption and farm income. Prior research on gender and CSA adoption often defines gender as female-headed versus male-headed households (Teklewold et al., 2019). This study defined gender based on the individuals within the household that owned, cultivated or managed a farm plot(s).

This study focused on the farmer's choice of five CSA practices – (intercropping with legumes (I), mixed cropping (M), improved seed (V), organic (O) and inorganic fertilisers (F) and their adoption impact on the income of crop farmers in Nigeria. The study emphasized the well-established benefits of intercropping with legumes and mixed cropping as CSA practices, drawing on research by (Rumpel & Chabbi, 2021; Yu et al., 2022). These benefits include improved farm income, productivity and crop resilience to climate change, enhanced soil health through increased biodiversity, organic matter promotion, and improved moisture retention. Other benefits include the disruption of pest and pathogen life cycles, leading to reduced outbreaks. Equally, the study acknowledges the role of organic and inorganic fertilizers as a climate-smart integrated nutrient management strategy that increases farm productivity, and income and boosts climate change resilience (Gram et al., 2020). Additionally, the research highlights the importance of improved seeds as a CSA practice that enhances farm productivity, farmer income, and resilience to climate challenges (Cacho et al., 2020). This study examined the factors influencing the multiple adoption of the five CSA practices (I, M, V, O and F) by male and female crop farmers in Nigeria, and the effect of their multiple adoption on the farmer's net farm income.

Methodology

This study was conducted in Nigeria, a country with a total area of 923,768 km², consisting of 909,890 km² of land and 13,879 km² of water (NBS, 2019). Nigeria is located between 3°E and 14°E longitudes and 4°N and 14°N latitudes (NBS, 2019). The economy is predominantly agrarian, supporting over 80% of the population and contributing approximately 27% to the GDP (NBS, 2022). The country has 71.2 million hectares of cultivable land, producing staple crops such as millet, maize, rice, sorghum, cocoyam, yam, and cassava, as well as cash crops like ginger, groundnuts, cocoa, cotton, oil palm, and sesame (NBS, 2023). The research utilized data from the Nigeria Generalized Household Survey (GHS) Panel, collected by the NBS during 2011/2012, 2013/2014 and 2015/2016. The GHS-Panel data set represents a cross-section of approximately 5,000 households from the country's six geopolitical zones.

In this study, we considered the rate of adoption of five different agricultural practices; intercropping with legumes (I), mixed cropping (M), improved seeds (V), organic (O), and inorganic fertilisers (F) as shown in Table 1. The selection of these five CSA practices was based on prior expectations that each can deliver one or more CSA goals. Adoption of practices was self-reported in response to yes/no questions. The farmer could choose from 28 combinations of these practices. For instance, the adoption of all the five CSA practices as $I_1M_1V_1F_1O_1$; the adoption of none is $I_0M_0V_0F_0O_0$; and so on. Equally, we considered the following control variables; household features: sex, age, marital status, education level, and household size. Wealth: farm size, off-farm activities, assets, tropical livestock unit, remittance, fertilizer subsidy, credit. Access to information: distance to road, distance to market, access to extension services, access to mobile phone and internet. Shock: health shock, climate shock, pest shock. Farm features: number of parcels, tenure, distance from house to the plot, plot slope, plot elevation, plot wetness, and Climate: temperature, precipitation, semiarid, sub-humid, humid. These control variables were deemed relevant because they cover a comprehensive range of factors that influence farmers' decision-making processes in adopting agricultural practices. By considering household demographics, economic status, information accessibility, environmental shocks, farm-specific characteristics, and climatic conditions, the study ensured a holistic understanding of the various elements impacting agricultural adoption decisions.

To understand the impact of CSA practices on farm income in Nigeria, we used advanced econometric techniques to address potential biases. We recognized that farmers' choices to adopt CSA practices might be influenced by factors not visible to researchers, leading to selection bias. Traditional methods, like ordinary least squares, can't handle this bias effectively. To tackle these issues, we combined endogenous switching regression and panel data analysis. First, we used a multivariate probit model to estimate individual heterogeneity over time and address selection bias. This helped us understand the adoption process while considering various factors like household characteristics, farm features, and climate conditions. The multivariate probit model is shown as follows:

$$U_{itk}^{*} = X_{it}'\beta_k + \propto + \varepsilon_{itk} \; (k = \mathrm{I, M, V, F, O}) \qquad (1)$$

Where X_{it}' is a matrix of climate and household features, β_k are estimation parameters, α is an unobserved time-constant heterogeneity and ε_{itk} is the disturbance/error term.

Next, we applied the Endogenous Switching Regression model to examine how these CSA practices impact farm income. By incorporating the likelihood estimates from the first model, we adjusted for any selection bias. This method allowed us to compare farmers who adopted CSA practices with those who didn't, under similar conditions. Finally, we used the Fixed Effects model to analyse the relationship between farm income and the specific combinations of CSA practices adopted by the households. This step accounted for unobserved household characteristics that remain constant over time.

Results and Discussion

Joint adoption probabilities of multiple climate-smart agricultural practices

The results of the rates of choice of the different CSA combinations as shown in Table 1 indicate that crop farmers in Nigeria adopted all the 28 possible combinations of CSA. The majority (23.52%) of the farmers used mixed cropping and improved seed ($I_0M_1V_1F_0O_0$) packages in their farming. This was followed by the 14.13% of the farmers who used mixed cropping, improved seed and inorganic fertilizer ($I_0M_1V_1F_1O_0$) packages. Others were used at varying degrees but the least share of farmers (0.14%) used intercropping with legumes and organic ($I_1M_0V_0F_0O_1$) packages in their farming. Importantly, about 5% of the farmers did not adopt any of the CSA combinations ($I_0M_0V_0F_0O_0$) in their farming.

The result of the joint and marginal probabilities of CSA combinations choice by gender status shows that 22.1% and 34.4% of male and female farmers used mixed cropping and improved seed ($I_0M_1V_1F_0O_0$) packages, respectively. About 14% of males used mixed cropping, improved seed and inorganic fertilizer ($I_0M_1V_1F_1O_0$) package while 11% of the female farmers used the package indicating a gap of about 3%. Equally, about 14% of the female farmers used only mixed cropping ($I_0M_1V_0F_0O_0$) package in their farming while 7.7% of the male farmers used the package, indicating a wide gap of 6.2%. It is important to note that none of the female farmers used intercropping with legumes, mixed cropping, and improved seed and organic fertilizer ($I_1M_1V_1F_0O_1$) packages in their farming; indicating that the female farmers used only 27 combinations of the CSA packages while the male farmers used all 28 packages.

This result implied that the farmers adopted a varying range of different CSA packages, which has consequences on food production, income and food security of the various households. With this set of available packages known, it is important to understand the drivers of the individual choice of specific packages for policy direction. This finding is similar to Chukwuone et al. (2021) who found that about 25% of farmers in Nigeria used cropping system diversification and improved seed CSA packages in their farming.

Table 1: Joint adoption probabilities of multiple climate-smart agricultural; characterizing choice by year and gender status, %

Choice (j)	Combinations (j)	Package Components						Joint prob.	Wave Year			Gender	
		I	M	V	F	O	Definition	All	2010	2012	2015	MHM	FHM
1	$I_0M_0V_0F_0O_0$	-	-	-	-	-	None	5.01	3.70	3.39	7.85	5.02	4.92
2	$I_1M_0V_0F_0O_0$	1	-	-	-	-	I only	1.15	1.07	037	2.05	1.16	1.13
3	$I_0M_1V_0F_0O_0$	-	1	-	-	-	M only	8.43	8.03	5.06	12.26	7.71	14.02
4	$I_0M_0V_1F_0O_0$	-	-	1	-	-	V only	9.77	9.24	9.08	10.96	9.57	11.35
5	$I_0M_0V_0F_1O_0$	-	-	-	1	-	F only	2.05	1.98	1.52	2.65	2.11	1.54
6	$I_0M_0V_0F_0O_1$	-	-	-	-	1	O only	0.19	0.11	0.03	0.44	0.18	0.27
7	$I_1M_1V_0F_0O_0$	1	1	-	-	-	I & M	3.78	4.36	5.10	1.89	3.83	3.35
8	$I_1M_0V_1F_0O_0$	1	-	1	-	-	I & V	2.69	3.54	2.86	1.75	2.80	1.87
9	$I_1M_0V_0F_1O_0$	1	-	-	1	-	I & F	0.61	0.38	0.37	1.08	0.66	0.22
10	$I_1M_0V_0F_0O_1$	1	-	-	-	1	I & O	0.14	0.01	0.01	0.39	0.12	0.30
11	$I_0M_1V_1F_0O_0$	-	1	1	-	-	M & V	23.52	28.45	31.45	10.91	22.13	34.39
12	$I_0M_1V_0F_1O_0$	-	1	-	1	-	M & F	5.48	5.59	3.52	7.41	5.59	4.67
13	$I_0M_1V_0F_0O_1$	-	1	-	-	1	M & O	1.37	0.31	0.27	3.46	1.33	1.70
14	$I_0M_0V_1F_1O_0$	-	-	1	1	-	V & F	4.11	4.62	4.44	3.31	4.38	2.01
15	$I_0M_0V_1F_0O_1$	-	-	1	-	1	V & O	0.71	0.27	0.22	1.61	0.67	1.07
16	$I_0M_0V_0F_1O_1$	-	-	-	1	1	F & O	0.36	0.17	0.09	0.80	0.36	0.36
17	$I_1M_1V_1F_0O_0$	1	1	1	-	-	I, M & V	3.35	4.37	4.63	1.12	3.64	1.13
18	$I_1M_0V_1F_1O_0$	1	-	1	1	-	I, V & F	1.61	2.01	1.93	0.91	1.76	0.38
19	$I_1M_0V_0F_1O_1$	1	-	-	1	1	I, F & O	0.17	0.05	0.00	0.44	0.18	0.03
20	$I_0M_1V_1F_1O_0$	-	1	1	1	-	M, V & F	14.13	16.30	17.63	8.56	14.47	11.46
21	$I_0M_1V_0F_1O_1$	-	1	-	1	1	M, F & O	1.62	0.13	0.11	4.51	1.69	1.07
22	$I_0M_0V_1F_1O_1$	-	-	1	1	1	V, F & O	0.48	0.27	0.08	1.08	0.46	0.63
23	$I_1M_1V_1F_1O_0$	1	1	1	1	-	I, M, V & F	3.63	3.45	5.57	1.81	4.05	0.41
24	$I_1M_0V_1F_1O_1$	1	-	1	1	1	I, V, F & O	0.18	0.14	0.05	0.33	0.19	0.03
25	$I_1M_1V_0F_1O_1$	1	1	-	1	1	I, M, F & O	0.67	0.08	0.15	1.73	0.74	0.08
26	$I_1M_1V_1F_0O_1$	1	1	1	-	1	I, M, V & O	1.07	0.45	0.68	2.03	1.20	0.00
27	$I_0M_1V_1F_1O_1$	-	1	1	1	1	M, V, F & O	2.61	0.67	0.96	6.06	2.76	1.43
28	$I_1M_1V_1F_1O_1$	1	1	1	1	1	I, M, V, F & O	1.11	0.22	0.45	2.61	1.24	0.16

Note: A subscript 1 indicates farmers' adoption choice while 0 indicates otherwise. No. Observation = 31,95.
Source: Author's calculations using GHS-Panel wave 1 – 3.

Factors influencing the adoption of multiple CSA practices by different gender

Model Fit and Correlation: The multivariate probit model with the Mundlak approach shown in Tables 2 and 3 demonstrated a strong model fit. The Wald chi2(235) statistic was 20698.32 (p=0.000), rejecting the null hypothesis and indicating a correlation between observed covariates and unobserved household fixed effects.

Adoption Heterogeneity: The likelihood ratio test (chi2(10) = 743.579, Prob > chi2 = 0.0000) suggested rejecting the null hypothesis of independence between the CSA practice adoption decisions. Eight of the estimated correlation coefficients (Rho) were statistically significant, indicating that certain CSA practice combinations were viewed as either alternatives or complements by farmers.

Complementary and Alternative Practices: The practice of intercropping with legumes and mixed cropping ($I_1M_1V_0F_0O_0$), intercropping with legumes and improved seeds ($I_1M_0V_1F_0O_0$), intercropping with legumes and inorganic fertilizers ($I_1M_0V_0F_1O_0$), intercropping with legumes and organic fertilizers ($I_1M_0V_0F_0O_1$), and organic and inorganic fertilizers ($I_0M_0V_0F_1O_1$) were found to be negatively significant, which infers that crop farmers consider the combination of these CSA practices as alternatives or incompatible. However, combinations such as mixed cropping and inorganic fertilizers ($I_0M_1V_0F_1O_0$), mixed cropping ($I_0M_1V_0F_0O_0$), and improved seed and organic fertilizers ($I_0M_0V_1F_0O_1$) were found to be positively significant, which infers that crop farmers mainly consider them as complements.

Influence of Demographics: The outcome of the MVP estimation in Table 3 shows that explanatory variables influence the probability of various packages or categories of CSA practices adoption.

Gender: It showed that at 1%, sex had a significant and negative effect on the adoption of mixed cropping, and inorganic and organic fertilizers. This means that males were less inclined to adopt mixed cropping, and organic and inorganic fertilizers ($I_0M_1V_0F_1O_1$) in isolation or combination than the females. This finding supports the findings of Chukwuone et al., (2021) that females were more inclined towards cost-effective practices.

Age: it showed that older farmers were significantly less likely to adopt intercropping with legumes and inorganic fertilizers ($I_1M_0V_0F_1O_0$) but more likely to adopt mixed cropping ($I_0M_1V_0F_0O_0$). This supports the findings that the adoption rate of CSA practices drops with further age increases (Negera et al., 2022).

Marital status: Married farmers were 31% and 11% more likely to adopt organic and inorganic fertilizers ($I_0M_0V_0F_1O_1$) compared to unmarried farmers.

Education: Educated farmers were 0.03%, 0.05%, and 0.02% more likely to adopt mixed cropping, inorganic, and organic fertilizers respectively, but 0.07% less likely to adopt improved seeds ($I_0M_0V_1F_0O_0$). According to Gikonyo et al., (2022), the literacy status of the household head/members positively influences their adoption of CSA practices. On the contrary, this study has through its finding that less-educated farmers adopted improved seeds more than the educated supported the findings of (Zakaria et al., 2020) that relative to highly educated farmers, less-educated farmers were more likely to adopt irrigation. This shows that education can equally influence adoption negatively as it offers farmers the rational choice of alternatives, which may be more productive.

Household and Farm Characteristics: Larger households were approximately 3% more likely to adopt intercropping with legumes and organic fertilizers ($I_1M_0V_0F_0O_1$) but 3% less likely to adopt improved seeds ($I_0M_0V_1F_0O_0$).

Other significant factors influencing CSA adoption included farm size, off-farm activities, assets, livestock units, remittance, fertilizer subsidy, and credit.

Access to Information and Services: Distance to roads and markets, extension services, and access to mobile phones and the internet were significant in influencing CSA practice adoption.

Environmental Factors: Health, climate, and pest shocks, along with plot characteristics like slope and wetness, and climatic zones, were significant in CSA adoption decisions.

Gender Gaps: The study revealed significant gender disparities in the adoption of various farming practices influenced by factors such as age, marital status, education level, household size, farm size, and other variables. Both younger male and female farmers are more likely to adopt all CSA practices compared to older farmers, suggesting greater openness to innovation among the youth. Marital status significantly impacts male farmers, with married men being less inclined to adopt certain practices. Education level shows contrasting effects: higher education negatively influences female farmers' adoption of all practices, possibly due to a disconnect between theoretical knowledge and practical application, while educated male farmers exhibit mixed adoption patterns, being selective about which practices to adopt. Larger households and farm sizes also affect adoption differently by gender; for instance, larger households negatively impact female farmers' adoption of multiple practices, while male farmers show both negative and positive influences depending on the specific practices. Additionally, variables like off-farm income, livestock units, and internet access significantly impact male farmers' decisions, while fertilizer subsidies and specific environmental conditions more strongly influence female farmers. These gender-specific differences highlight the need for tailored interventions to support both male and female farmers effectively.

Table 2: CSA correlation error term

CSA combinations	Coefficient	Std. Error
$I_1M_1V_0F_0O_0$	-.0674391***	.0099331
$I_1M_0V_1F_0O_0$	-.1965599***	.0093881
$I_1M_0V_0F_1O_0$	-.0518144 ***	.009844
$I_1M_0V_0F_0O_1$	-.0334154 **	.0134143
$I_0M_1V_1F_0O_0$	.0073218	.0092386
$I_0M_1V_0F_1O_0$	.069908***	.0094897
$I_0M_1V_0F_0O_1$	.1424507***	.0129386
$I_0M_0V_1F_1O_0$	.009753	.0091914
$I_0M_0V_1F_0O_1$	0767858***	.0124063
$I_0M_0V_0F_1O_1$	-.0680487***	.0121598

NB: Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2(10) = 743.579 Prob > chi2 = 0.0000
*** & ** significance at 1% & 5% confidence level.
Intercropping with legumes (I), mixed cropping (M), improved seed (V), inorganic fertilisers (F) and organic fertilisers (O)

Source: Author's calculations using GHS-Panel data wave 1 – 3.

Table 3: Parameter estimates of the multivariate probit model with Mundlak approach – choice of CSA strategies

	Intercropping with legumes (I)		Mixed Cropping (M)		Improved seed (V)		Inorganic fertilizer (F)		Organic fertilizer (O)	
Variables	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**	**Coefficient**	**Std. Error**
Sex	0.058	0.044	-0.112***	0.036	0.041	0.035	-0.241***	0.038	-0.220***	0 .053
Age (yrs)	-0.002**	0.001	0.001*	0.001	-0.000	0.001	-0.007***	0.001	0.001	0.001
M Status	-0.011	0.035	0.032	0.030	0.017	0.029	0.305***	0.032	0.111***	0.043
Edu level (yrs)	0.000	0.001	0.003***	0.001	-0.007***	0.001	0.005***	0.001	0.002**	0.001
HHsize	0.028**	0.011	0.042***	0.010	-0.029***	0.010	0.009	0.010	0.0265*	0.014
Farm size (ha)	0.000	0.000	-0.000***	0.000	-0.000***	0.000	0.000***	0.000	-0.000**	0.000
Offarm	-0.065**	0.030	0.019	0.027	0.075***	0.027	-0.048*	0.027	-0.033	0.039
Asset (Naira)	2.83e	4.00e	-1.10e***	3.27e	8.03e**	3.17e	-5.74e	3.29e	-2.09e	3.12e
TLU	-0.000	0.000	0.002	0.001	-0.002	0.001	0.006***	0.002	0.001**	0.000
Remittance	0.200**	0.085	0.100	0.077	0.293***	0.071	0.251***	0.073	0.071	0.095
Fert subsdy	-0.081	0.078	-0.213***	0.082	-0.024	0.074	0.479***	0.076	0.893***	0.079
Credit	0.085***	0.023	0.023	0.021	0.226***	0.021	0.066***	0.021	0.072**	0.033
Dist road (km)	-0.003***	0.001	0.002***	0.001	0.003***	0.001	0.001**	0.001	-0.001	0.001
Dist mrkt (km)	0.000	0.000	-0.001***	0.000	0.000	0.000	-0.006***	0.000	-0.003***	0.000
Extension	0.063***	0.024	-0.009	0.024	-0.190***	0.022	0.240***	0.023	0.024	0.030
Mobile	0.018	0.027	0.046*	0.025	0 .019	0.025	0 .082***	0.025	0.162***	0.037
Internet	-0.019	0.034	-0.122***	0.030	-0.138***	0.029	-0.074**	0.030	-0.280***	0.045
Health shock	-0.013	0.033	0.037	0.030	-0.069**	0.029	-0.047	0.030	-0.018	0.043
Climate shock	0.105***	0.035	0.047	0.034	-0.061*	0.034	-0.011	0.034	-0.100**	0.047
Pest shock	0.006	0.081	0.320***	0.082	-0.121	0.077	-0.080	0.078	-0.194*	0.111
Numb parcel	0.028***	0.003	0 .087***	0.003	-0.003	0.003	0 .006**	0.003	0.055***	0.004
Tenure	0.006	0.024	0.031	0.022	0.080***	0.021	0.048**	0.022	0.070**	0.032
Plot dist (km)	0.000	0.000	0.000	0.000	-0.000*	0.000	0.000	0.000	-0.001	0.001
Plot slop	0.004	0.003	-0.003	0.003	-0.014***	0.003	-0.029***	0.003	-0.050***	0.006
Plot elevation	0.000***	0.000	-0.000**	0.000	-0.000***	0.000	0.002***	0.000	0.001***	0.000
Plot wetness	0.001	0.003	-0.003	0.003	-0.003	0.003	-0.009***	0.003	-0.004	0 .004
Temperature	-0.193	0.136	-0.128	0.121	-0.274**	0.132	-0.017	0.127	-0.203	0.239
Precipitation	-0.001	0.001	0.000	0.001	0 .001*	0.001	0.001*	0.001	0.001	0.001
Semi-arid	0.989***	0.099	0.365***	0.082	-0.714***	0.091	-0.341***	0.103	0.587***	0.113
Sub-humid	1.101***	0.101	-0.564***	0.084	-0.741***	0.093	-0.893***	0 .103	-0.105	0.119
Humid	1.263***	0.120	-0.950***	0.093	-0.654***	0.102	-1.223***	0.112	0.081	0.137
Wave 1	0.106**	0.045	0.362***	0.042	0.389***	0.041	-0.430***	0.042	-1.037***	0 .058
Wave 2	0.174***	0.026	0.378***	0.024	0.577***	0.024	-0.056**	0.024	-1.184***	0.035
Constant	1.968***	0.467	-2.714***	0.413	0.188	0 .427	-1.183***	0.407	-4.180***	0.676
Observation			33784							
Chi-Square			Wald chi2(235) = 20698.32				Prob > chi2 = 0.0000			

Source: Author's calculations using GHS-Panel data wave 1 – 3.

Impact of adoption of multiple CSA practices on the net income of the farmers

Table 4 shows that adopting CSA practices leads to higher net farm income compared to not adopting these practices. The highest net farm income from adopting a single CSA practice was achieved with the use of inorganic fertilizer ($I_0M_0V_0F_1O_0$), amounting to 167.54 thousand Naira per hectare. When two CSA practices were adopted (intercropping with legumes and inorganic fertilizer ($I_1M_0V_0F_1O_0$)), the income gain increased to 252.75 thousand Naira per hectare. Further increases were observed with the adoption of three CSA practices ($I_1M_0V_1F_1O_0$), resulting in a gain of 2636.66 thousand Naira per hectare, and four CSA practices ($I_0M_1V_1F_1O_1$), leading to a gain of 9743.90 thousand Naira per hectare. Interestingly, the income from adopting all five CSA practices was generally lower than the income from adopting fewer practices.

The results suggest that adopting CSA practices positively impacts farm income, supporting the notion that these practices enhance agricultural productivity and profitability. However, the variability in income effects based on the number and combination of practices adopted indicates that certain combinations may be more effective than others. The highest income gains were observed with the adoption of $I_0M_1V_1F_1O_1$ rather than all five practices together. This may imply diminishing returns or increased complexity and cost when too many practices are combined. These findings are consistent with the study by Chukwuone et al., (2021), which also reported higher economic gains from the combined adoption of CSA practices.

Table 4: Average expected net farm income outcome with the adoption of different CSA strategies

CSA Combinations (j)	Actual farm net income (Adopted) A (j = 2,3,4,5…28)	Counterfactual farm net income (Not Adopted) B (j = 1)	Effects of Adoption C
$I_1M_0V_0F_0O_0$	82.43 (2.73)	56.62 (1.66)	25.81 (2.63)
$I_0M_1V_0F_0O_0$	79.21 (0.39)	60.78 (0.88)	18.43 (1.02)
$I_0M_0V_1F_0O_0$	93.95 (0.43)	55.45 (0.77)	38.50 (0.74)
$I_0M_0V_0F_1O_0$	231.39 (17.23)	63.85 (1.27)	167.54 (16.61)
$I_0M_0V_0F_0O_1$	125.81 (0.23)	68.52 (4.51)	57.30 (4.45)
$I_1M_1V_0F_0O_0$	108.41 (57.71)	52.59 (1.17)	55.83 (57.97)
$I_1M_0V_1F_0O_0$	81.02 (1.54)	57.00 (1.42)	24.02 (2.76)
$I_1M_0V_0F_1O_0$	311.66 (38.25)	58.91 (2.33)	252.75 (38.18)
$I_1M_0V_0F_0O_1$	121.63 (0.14)	41.84 (5.98)	79.79 (5.95)
$I_0M_1V_1F_0O_0$	112.12 (0.52)	61.58 (0.46)	50.53 (0.60)
$I_0M_1V_0F_1O_0$	126.25 (1.66)	71.93 (0.74)	54.33 (1.97)
$I_0M_1V_0F_0O_1$	121.17 (3.12)	77.36 (1.71)	43.80 (3.53)
$I_0M_0V_1F_1O_0$	160.23 (1.24)	57.17 (0.87)	103.06 (1.59)
$I_0M_0V_1F_0O_1$	117.10 (3.95)	57.64 (3.08)	59.46 (5.47)
$I_0M_0V_0F_1O_1$	126.71 (0.09)	83.41 (3.12)	43.30 (3.14)
$I_1M_1V_1F_0O_0$	175.74 (5.11)	75.17 (1.20)	100.57 (5.67)
$I_1M_0V_1F_1O_0$	2694.53 (80.57)	57.88 (1.54)	2636.66 (80.29)
$I_1M_0V_0F_1O_1$	104.77 (0.52)	73.47 (4.00)	31.30 (4.16)
$I_0M_1V_1F_1O_0$	143.12 (1.42)	73.41 (0.50)	69.71 (1.68)
$I_0M_1V_0F_1O_1$	120.65 (0.20)	89.22 (1.98)	31.43 (2.03)
$I_0M_0V_1F_1O_1$	82.29 (0.25)	73.69 (2.67)	8.60 (2.72)
$I_1M_1V_1F_1O_0$	172.53 (3.30)	90.95 (0.77)	81.57 (3.09)
$I_1M_0V_1F_1O_1$	120.12 (2.07)	80.70 (3.41)	39.42 (4.20)
$I_1M_1V_0F_1O_1$	120.96 (0.11)	102.89 (4.19)	18.07 (4.21)
$I_1M_1V_1F_0O_1$	535.30 (31.26)	102.28 (1.23)	433.02 (31.78)
$I_0M_1V_1F_1O_1$	9836.45 (273.61)	92.55 (0.86)	9743.90 (273.68)
$I_1M_1V_1F_1O_1$	182.36 (4.47)	102.24 (1.00)	80.13 (4.55)

Source: Author's calculations using GHS-Panel data wave 1 – 3.

Gender gaps and average effects on the adoption of different CSA strategies

The result of the disaggregated gender analysis presented in Appendix 1 for the average heterogeneity effects on farm revenue for FHMs, if FHMs characteristics had the same returns as MHMs with each combination of CSA practices reveals an overall gender difference in different combinations of CSA practice categories due to gender and heterogeneity gaps. All the MHMs adoption of any of the CSA practices were better off in the actual scenarios (adopters) while the FHMs were better off in the counterfactual scenarios (non-adoption), except for the adopters of $I_0M_1V_0F_0O_0$, $I_0M_0V_0F_0O_1$, $I_1M_0V_1F_0O_0$, $I_1M_0V_0F_0O_1$, $I_0M_1V_1F_0O_0$, $I_0M_1V_0F_1O_0$, $I_0M_0V_1F_1O_0$, $I_1M_1V_1F_0O_0$, $I_0M_1V_1F_1O_0$ and $I_1M_1V_1F_1O_1$.

This means that the adoption of a combination of CSA practices by the MHMs provides positive net farm income compared with non-adoption while for FHMs, aside from the adoption of $I_0M_1V_0F_0O_0$, $I_0M_0V_0F_0O_1$, $I_1M_0V_1F_0O_0$, $I_1M_0V_0F_0O_1$, $I_0M_1V_1F_0O_0$, $I_0M_1V_0F_1O_0$, $I_0M_0V_1F_1O_0$, $I_1M_1V_1F_0O_0$, $I_0M_1V_1F_1O_0$ and $I_1M_1V_1F_1O_1$, which provides positive outcomes, all other CSA combinations provide negative net farm income compared with non-adoption, suggesting availability of other better options. The result supports (Apeh et al., 2024; Apeh et al., 2023a; Ohagwu et al., 2024), that improving FHMs' access to essential agricultural resources is crucial to improving their productive potential and income.

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Conclusion and Recommendations

Farmers who implemented a wider range of CSA practices experienced a significant increase in net farm income. A concerning gender gap emerged in the adoption of CSA practices. Male farmers generally experienced greater benefits in terms of income compared to their female counterparts. The study recommends that CSA interventions must prioritize promoting gender equality in resource access and control.

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Appendix 1: Gender gaps and average effects on the adoption of different CSA strategies

Combinations (j)	Outcome	MHM	FHM	Response effect (MHM – FHM)
$I_1M_0V_0F_0O_0$	$E(Q_2 \mid g=MHM)$	79.076	70.526	8.55
	$E(Q_2 \mid g=FHM)$	45.049	492.205	-447.156
	Heterogeneity effect	34.027	-421.679	
$I_0M_1V_0F_0O_0$	$E(Q_2 \mid g=MHM)$	79.955	693.889	-613.934
	$E(Q_2 \mid g=FHM)$	51.741	152.847	-101.106
	Heterogeneity effect	28.214	541.042	
$I_0M_0V_1F_0O_0$	$E(Q_2 \mid g=MHM)$	103.708	151.614	-47.906
	$E(Q_2 \mid g=FHM)$	44.88	211.016	-166.136
	Heterogeneity effect	58.828	-59.402	
$I_0M_0V_0F_1O_0$	$E(Q_2 \mid g=MHM)$	273.817	1065.732	-791.915
	$E(Q_2 \mid g=FHM)$	53.222	1644.937	-1591.72
	Heterogeneity effect	220.595	-579.205	
$I_0M_0V_0F_0O_1$	$E(Q_2 \mid g=MHM)$	118.942	141.027	-22.085
	$E(Q_2 \mid g=FHM)$	53.601	115.438	-61.837
	Heterogeneity effect	65.341	25.589	
$I_1M_1V_0F_0O_0$	$E(Q_2 \mid g=MHM)$	307.881	-5353.234	5661.115
	$E(Q_2 \mid g=FHM)$	42.858	277.606	-234.748
	Heterogeneity effect	265.023	-5630.84	
$I_1M_0V_1F_0O_0$	$E(Q_2 \mid g=MHM)$	81.099	3748.048	-3666.95
	$E(Q_2 \mid g=FHM)$	44.385	280.51	-236.125
	Heterogeneity effect	36.714	3467.538	
$I_1M_0V_0F_1O_0$	$E(Q_2 \mid g=MHM)$	708.868	109.794	599.074
	$E(Q_2 \mid g=FHM)$	49.219	787.532	-738.313
	Heterogeneity effect	659.649	-677.738	
$I_1M_0V_0F_0O_1$	$E(Q_2 \mid g=MHM)$	124.858	109.16	15.698
	$E(Q_2 \mid g=FHM)$	36.071	46.768	-10.697
	Heterogeneity effect	88.787	62.392	
$I_0M_1V_1F_0O_0$	$E(Q_2 \mid g=MHM)$	115.427	421.317	-305.89

	$E(Q_2 \mid g=FHM)$	53.005	154.596	-101.591
	Heterogeneity effect	62.422	266.721	
$I_0M_1V_0F_1O_0$	$E(Q_2 \mid g=MHM)$	131.95	685.663	-553.713
	$E(Q_2 \mid g=FHM)$	58.992	670.427	-611.435
	Heterogeneity effect	72.958	15.236	
$I_0M_1V_0F_0O_1$	$E(Q_2 \mid g=MHM)$	106.54	86.396	20.144
	$E(Q_2 \mid g=FHM)$	61.69	106.087	-44.397
	Heterogeneity effect	44.85	-19.691	
$I_0M_0V_1F_1O_0$	$E(Q_2 \mid g=MHM)$	163.601	4373.175	-4209.57
	$E(Q_2 \mid g=FHM)$	47.421	603.546	-556.125
	Heterogeneity effect	116.18	3769.629	
$I_0M_0V_1F_0O_1$	$E(Q_2 \mid g=MHM)$	127.734	106.304	21.43
	$E(Q_2 \mid g=FHM)$	48.881	161.199	-112.318
	Heterogeneity effect	78.853	-54.895	
$I_0M_0V_0F_1O_1$	$E(Q_2 \mid g=MHM)$	129.336	111.578	17.758
	$E(Q_2 \mid g=FHM)$	64.9	405.774	-340.874
	Heterogeneity effect	64.436	-294.196	
$I_1M_1V_1F_0O_0$	$E(Q_2 \mid g=MHM)$	122.822	5598.985	-5476.16
	$E(Q_2 \mid g=FHM)$	58.044	210.901	-152.857
	Heterogeneity effect	64.778	5388.084	
$I_1M_0V_1F_1O_0$	$E(Q_2 \mid g=MHM)$	2702.368	110.516	2591.852
	$E(Q_2 \mid g=FHM)$	47.69	447.869	-400.179
	Heterogeneity effect	2654.678	-337.353	
$I_0M_1V_1F_1O_0$	$E(Q_2 \mid g=MHM)$	167.521	6544.527	-6377.01
	$E(Q_2 \mid g=FHM)$	60.343	190.462	-130.119
	Heterogeneity effect	107.178	6354.065	
$I_0M_1V_0F_1O_1$	$E(Q_2 \mid g=MHM)$	122.532	102.02	20.512
	$E(Q_2 \mid g=FHM)$	70.513	239.511	-168.998
	Heterogeneity effect	52.019	-137.491	
$I_0M_0V_1F_1O_1$	$E(Q_2 \mid g=MHM)$	83.044	74.785	8.259
	$E(Q_2 \mid g=FHM)$	60.136	1957.137	-1897
	Heterogeneity effect	22.908	-1882.35	
$I_1M_1V_1F_1O_0$	$E(Q_2 \mid g=MHM)$	161.325	235.73	-74.405
	$E(Q_2 \mid g=FHM)$	71.684	267.614	-195.93
	Heterogeneity effect	89.641	-31.884	
$I_1M_1V_0F_1O_1$	$E(Q_2 \mid g=MHM)$	121.534	73.699	47.835
	$E(Q_2 \mid g=FHM)$	77.822	391.415	-313.593
	Heterogeneity effect	43.712	-317.716	
$I_0M_1V_1F_1O_1$	$E(Q_2 \mid g=MHM)$	32690.915	113.587	32577.33
	$E(Q_2 \mid g=FHM)$	73.174	155.74	-82.566
	Heterogeneity effect	32617.74	-42.153	
$I_1M_1V_1F_1O_1$	$E(Q_2 \mid g=MHM)$	172.722	143.585	29.137
	$E(Q_2 \mid g=FHM)$	79.054	136.197	-57.143
	Heterogeneity effect	93.668	7.388	

Source: Own calculations using Generalized Household Survey (GHS-Panel) wave 1 – 3