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Land Tenure Security, Crop Choices, and Agricultural Input Investment Decisions

Evidence from Nationally Representative Data in Nigeria

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Abstract

Land tenure security is widely regarded as essential for agricultural investment and productivity growth. However, causal evidence on its effects across multiple farm decisions remains limited, particularly in sub-Saharan Africa. This study investigates how tenure security is associated with crop portfolio choices and input investment decisions among smallholder farmers in rural Nigeria. It measures tenure security using a composite index, drawn from wave 5 of the Nigeria Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA), that captures plot-level perceived security of ownership, and household reported risk of land loss, ownership security, and duration of ownership. The study employs two complementary approaches: a multivariate probit model to capture the joint and correlated nature of crop adoption decisions, and limited information maximum likelihood instrumental variables (LIML-IV) estimation to establish association between land tenure and input investment decisions. Results reveal significant but heterogeneous effects. Greater tenure security increases the probability of cultivating grains and cereals by 29.8 percentage points, while reducing the likelihood of growing legumes and pulses by 24.6 percentage points and horticulture by 11.4 percentage points respectively, which suggests a substitution effect toward grain specialization. On input investments, LIML-IV estimates indicate that a one-unit increase in the tenure security index raises organic fertilizer use by 9.93 percent, inorganic fertilizer use by 6.57 percent, and pesticide use by approximately 0.89 percent. These findings are robust to Lewbel's heteroskedasticity-based identification strategy. Heterogeneity analysis reveals stronger investment effects among youth-headed households, while impacts on female-managed plots are statistically insignificant, pointing to persistent gender barriers. The study highlights the need for integrated policies that combine tenure formalization with crop diversification support, gender- and youth-sensitive land governance, and input market development in order to maximize the productivity gains from land rights reform in Nigeria.

Keywords: Land tenure security, property rights, land certification, crop choices, and agricultural input investment decisions.

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1. Introduction

Land tenure is a foundational structural constraint on agricultural transformation. A growing body of evidence links stronger tenure security to increased investment in sustainable land management and investments, and measurable productivity gains, though effect sizes vary substantially with institutional context and the resilience of customary governance arrangements (Dabessa Iticha & Han, 2025; Besley, 1995; Banerjee and Ghatak, 2004; Abdulai et al., 2011; Bambio and Agha, 2018; Paltasingh et al., 2022).

Li et al. (2022) demonstrate how land circulation reforms in the Pearl River Delta strengthened farmers' confidence in long-term contracts, translating into greater engagement in sustainable practices and measurable productivity gains. Beyond productivity, secure tenure systems are associated with improved household food security (Tesfaye et al., 2023) and long-term investment through diversified crop portfolios. In Nigeria, emerging evidence links more secure ownership and transfer rights to higher yields, reduced downside risk, and greater adoption of climate-smart practices, including agroforestry, residue retention, and conservation tillage, while tenure insecurity and land disputes remain structural barriers to rural transformation (Shittu et al., 2018; Kehinde et al., 2022; Olagunju et al., 2023).

These dynamics are especially pronounced in Nigeria, where the land tenure landscape remains particularly fragile. Less than 3 percent of all land is formally registered, and less than 12 percent of farming households hold any legal title, leaving most plots governed by customary or informal arrangements with weak documentation (Ghebru & Girmachew, 2017; NBS/World Bank, 2019). This pluralistic tenure regime, in which statutory, customary, and informal claims coexist, provides de facto access for many rural households but frequently fails to deliver the transferability, collateral value, and dispute protection that underpin long-term investment and efficient land use (Ghebru et al. 2014; Shittu et al., 2018). Substantial progress is therefore still needed to strengthen tenure security and expand the decision-making autonomy of farmers (Ghebru & Kennedy, 2019; FMARD, 2022).

More troubling still, these challenges fall disproportionately on rural youth, who sit at the intersection of a demographic bulge and a fragile rural labor market. Despite agriculture absorbing a sizable share of young workers, most participate under conditions of limited land control, weak documentation, and insecure rights (Adekemi, 2021; Kidido et al., 2017). Most rural youth farm without exclusive ownership or transferable rights, relying instead on family or communal access arrangements, and are consequently less likely than older farmers to access credit, extension services, or farmer organizations, which are the institutional levers critical to agricultural transformation (Kidido et al., 2017; Mwale & Ricker-Gilbert, 2025). This structural disadvantage erodes their capacity to invest, upgrade practices, or transition into higher-value agribusiness pathways.

Despite a growing body of research, the relationship between land tenure security and agricultural investment decisions remains empirically contested. No consensus has emerged on whether or how tenure security shapes crop choices and farm-level investments. Neglecting this institutional dimension risks distorting our understanding of smallholder behavior (Besley and Ghatak, 2010). On one hand, a substantial strand of the literature supports the proposition that more secure land rights incentivize investment. Studies examining farm-level investment, productivity, efficiency, and technology adoption have consistently found positive associations between tenure security and agricultural intensification (Place and Hazell, 1993; Besley, 1995; Li et al., 1998; Banerjee and Ghatak, 2004; Jacoby and Mansuri, 2009; Abdulai et al., 2011; Ali et al., 2012; Bambio and Agha, 2018; Paltasingh et al., 2022).

On the other hand, several studies find little or no evidence of this relationship. Holden and Yohannes (2002), and Pender and Fafchamps (2006) report findings that contradict the tenure–investment hypothesis, while Migot-Adholla et al. (1994) and Pinckney and Kimuyu (1994) find that land rights exert limited influence on soil improvement investments and tree crop planting. Place and Hazell (1993) similarly demonstrate that, with few exceptions, land rights were not significant determinants of land investment decisions. This mixed evidence underscores the context-dependence of the tenure–investment relationship and highlights the need for rigorous, country-specific analysis accounting for the institutional, agronomic, and socioeconomic conditions under which land rights operate. Notably, however, comparatively little attention has been paid to how land rights shape crop portfolio decisions. The limited evidence available suggests that tenure-secure farmers are more likely to allocate land to higher-value or longer-gestation crops, reflecting reduced expropriation risk and longer investment horizons (Deininger and Jin, 2006; Lawry et al., 2017).

This paper uses data from the Nigeria Nigeria Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) Wave 5, the most recent round of the survey, to examine how tenure security shapes smallholder farmers' input use and crop portfolio decisions. Using fixed effects estimation and instrumental variable approaches to address endogeneity concerns, the analysis exploits within-household variation across plots to identify the associations between land rights and agricultural investment behavior.

This study makes four main contributions to the literature on land tenure security and agricultural investment in sub-Saharan Africa. First, it provides new evidence on the effect of tenure security on crop choices and farm investment decisions, with particular attention to critical farm input investments that account for the majority of variable production costs for smallholder farming households. While a substantial body of work documents positive associations between secure tenure and long-term investments, such as tree planting and soil conservation (Besley, 1995), fewer studies examine modern variable input investments, such as fertilizers, herbicides, and pesticides, or how tenure shapes crop choice decisions.

Second, the paper advances methodological rigor by addressing endogeneity through three complementary strategies: a control function approach that formally tests and corrects for endogeneity; limited information maximum likelihood (LIML) instrumental variables estimation using plot inheritance as a plausibly exogenous instrument; and Lewbel's (2012) heteroskedasticity-based estimator as a robustness check. LIML is preferred here over alternatives such as two-stage least squares (2SLS) or generalized method of moments (GMM), given its superior finite-sample properties and greater robustness to weak instruments, which is a relevant concern when instrumenting for tenure security. Together, this multi-method design, an approach that is relatively limited in the tenure–investment literature, strengthens confidence that the findings are not driven by any single identification assumption.

Third, the paper contributes to ongoing debates around the measurement of tenure security. The empirical relationship between tenure security and agricultural investment is sensitive to how tenure is defined and operationalized, and this context-dependence partly explains the mixed findings in the literature (Arnot et al., 2011; Beekman and Bulte, 2012). In some settings, tenure security is equated with formal legal title; in others, it reflects the subjective confidence derived from customary rights and community recognition. Neither definition alone fully captures the multidimensional nature of land rights as experienced by smallholder farmers. This study addresses this limitation by constructing a composite tenure security index that integrates both objective and subjective elements, namely ownership security, formal documentation, duration of possession, and perceived risk of loss. This approach is particularly appropriate for the Nigerian context, where customary tenure systems predominate and formal titling remains limited, and it provides a more pragmatic and comprehensive measure of the land rights that actually govern farmer behavior and investment incentives.

Fourth, the study documents important heterogeneity by age and gender, with clear policy implications, contributing nuance to the growing literature on youth and women in African agriculture (FAO, 2018; Doss et al., 2018). Youth-specific dynamics remain underexplored: existing studies seldom differentiate how young farmers respond to changes in tenure security, despite evidence that youth face systematically weaker rights and more limited access to complementary services (Kidido et al., 2017).

Finally, by focusing on Nigeria, home to one of the largest smallholder farming populations in Africa yet the subject of relatively few causal studies on crop choice and input investment decisions, this paper fills an important contextual gap in the literature. This specificity matters because empirical evidence reveals substantial variation across socioeconomic, institutional, and geographic contexts, with the literature presenting conflicting and at times contradictory conclusions (Place, 2009; Abdulai et al., 2011; Lawry et al., 2017; Singirankabo and Ertsen, 2020). These divergent findings reflect the extent to which the tenure–investment nexus is conditioned by local land governance structures, the definition and measurement of tenure security, and the broader agronomic and market environment in which farmers operate.

The remainder of this paper is organized as follows. Section 2 presents the conceptual framework. Section 3 outlines the methodological framework and data. Section 4 presents empirical results. Section 5 discusses the findings in the context of Nigeria's agricultural policy landscape. Section 6 concludes with key insights and policy implications.

2. Conceptual Framework

Economic theory predicts that weak land tenure security discourages optimal investment in farmland. When farmers lack confidence in their ownership or usage rights, they are less willing to invest in improvements whose benefits accrue over time (Banerjee and Ghatak, 2004; Fenske 2001; Paltasingh, 2018). Smallholder investment decisions are shaped by the certainty with which land rights are held and the expectation of recouping returns from those investments (Goldstein & Udry, 2008). In rural Nigeria, where customary tenure systems dominate and inheritance is the primary mode of land acquisition, tenure insecurity often discourages the adoption and intensification of modern inputs such as organic and inorganic fertilizers, herbicides, and pesticides.

This study is grounded in a conceptual framework linking land tenure security to agricultural input investment through two main channels. The first channel is investment security. Secure tenure reduces the risk of expropriation and increases farmers' confidence in receiving future returns. Farmers with stronger rights, reflected in secure ownership status, formal documentation, longer duration of possession, and lower perceived risk of dispossession, are more likely to invest in soil fertility and crop protection inputs whose benefits accumulate over multiple seasons. By raising the expected marginal returns to inputs, tenure security also encourages more fertilizer use and shapes crop portfolio decisions. Specifically, tenure-secure farmers may favor grain crops over pulses and legumes, as grains tend to offer more immediate and predictable returns and respond more strongly to the input investments that secure tenure incentivizes. On the other hand, stronger land rights may also support shifts toward higher-value and longer-gestation crops, reflecting the longer and more secure planning horizons that tenure security affords.

The second channel is improved credit and liquidity access. Secure tenure, whether formal or perceived, enhances access to collateralized credit, extension services, and input markets, thereby easing financial constraints on higher input intensity (Besley, 1995; Deininger and Jin 2006). This is especially relevant in sub-Saharan Africa, where limited access to formal credit and insurance is a major barrier to technology adoption. Without mechanisms to buffer against risks such as crop failure, drought, or pest infestation, risk-averse smallholders tend to underinvest in modern inputs such as improved seeds, chemical fertilizers, and pesticides (Karlan et al., 2014; Dercon & Christiaensen, 2011; Lamb, 2003). By increasing the collateral value of land and signaling creditworthiness, tenure security can partially alleviate these constraints.

Overall, the framework predicts that a higher tenure security index will causally increase the intensity of agricultural input use among smallholder farmers. Conversely, insecure or contested land rights weaken investment incentives, perpetuating low productivity and input poverty in rural Nigeria.

3. Data Sources and Variable Measurement

This study draws on Wave 5 (2023/24) of the LSMS-ISA for Nigeria, which captures detailed household-level information on demographic characteristics, assets, agricultural production, and income sources. The underlying sample originates from Wave 4 (2018/19), which was designed as a nationally representative survey using a stratified two-stage cluster sampling procedure. In the first stage, enumeration areas (EAs) were randomly selected, and in the second stage, approximately 10 households were randomly selected within each EA, with stratification across the six geopolitical zones and urban/rural sectors. Wave 5 re-interviewed the same Wave 4 households, constituting a panel follow-up, with split-off households tracked to their new locations to minimize attrition (NBS & World Bank, 2021; 2024). The Wave 5 sample covers over 5,000 households across 519 EAs.

The analysis is restricted to farm households engaged in crop production with available plot-level tenure information, consistent with the study's focus on land tenure security, crop choices, and farm input investments. Households with no landholdings or without active farming on any plot were excluded. The final analytical sample comprises 4,667 plots, drawing on plot-level and household-level socioeconomic and land tenure characteristics.

3.1 Variable Construction

3.1.1 Land tenure security index

The key explanatory variable is a composite tenure security index ranging from 0 to 1. We construct four binary components at the plot level: Ownership security equals 1 if the plot was acquired through purchase or inheritance, and 0 otherwise. Formal documentation equals 1 if the household possesses a formal document for the plot, and 0 otherwise. Long duration of possession equals 1 if the household has possessed the plot for more than 10 years, and 0 otherwise. Perceived low risk of loss equals 1 if the respondent reports a low perceived risk of losing the plot, and 0 otherwise. The plot-level index is then calculated as the simple average of these four equally weighted components. Higher values indicate stronger overall tenure security.

This multidimensional structure reflects the bundle-of-rights approach in the land tenure literature, which recognizes that tenure security is not captured by any single indicator alone (Deininger & Feder, 2009; Place, 2009). The four components correspond to distinct dimensions that recur across Sub-Saharan Africa measurement frameworks: acquisition mode as a signal of rights strength (Bambio & Agha, 2018), formal documentation grounded in Nigeria's Land Use Act (1978) threshold between statutory and informal titles (Ghebru & Girmachew, 2017), duration of possession as a de facto tenure signal in customary systems (Sjaastad & Bromley, 1997; Place, 2009), and perceived risk of loss as a behaviorally relevant dimension independent of formal status. Equal weighting is applied, given that each component captures a conceptually distinct and theoretically justified dimension, making differential weighting difficult to justify without stronger empirical grounds (Alkire & Foster, 2011).

3.1.2. Input investments

The four dependent variables measure input-use intensity: the quantity (kg/ha) of organic fertilizer, inorganic fertilizer, herbicides, and pesticides applied per crop plot. Given that input usage is highly skewed and contains a large proportion of zero values, all four variables are log-transformed using the log(1+x) transformation, which accommodates zero values in the distribution while reducing the influence of extreme observations.

3.1.3. Crop choices

Crop choice outcomes were constructed by assigning each crop reported at the household level to one of four agronomic categories based on LSMS-ISA Wave 5 crop codes: cereals and grains (maize, sorghum, millet, rice), pulses and legumes (cowpea, soybean, groundnut), roots and tubers (cassava, yam, cocoyam, sweet potato), and horticulture (tomato, pepper, okra, banana, mango). This classification follows the crop frequency distribution in the Wave 5 dataset, ensuring broad coverage of cultivated crops rather than restricting attention to major staples alone. Crops with insufficient plot-level observations for reliable estimation were excluded, and their marginal share of total cultivated area makes this unlikely to affect the main findings.

Binary indicator variables were then generated for each category at the crop-observation level and collapsed to the plot level by taking the maximum value across all crops grown on a given plot, so that a plot received a value of one for a category if at least one crop in that category was cultivated on it. This procedure yielded plot-level binary indicators capturing the breadth of crop portfolio choices made by Nigerian smallholder households during the planting season.

Although the horticulture category combines tree crops with short-cycle field crops, this grouping is defensible in a cross-sectional setting where observed crop choices reflect longer-term decisions made under prevailing tenure conditions rather than short-term transitions, making the difference in investment horizons between crop types less consequential for the analysis (Goldstein & Udry 2008).

3.2 Descriptive Statistics

Table 1 presents summary statistics of key household, farm, and institutional variables. Overall, the sample is characterized by relatively older, predominantly rural farming households with moderate access to assets and limited adoption of modern inputs.

The average tenure security index is 0.397, indicating generally low-to-moderate perceived land tenure security among households. This suggests that a significant proportion of farmers operate under uncertain land rights, which may have implications for long-term investment decisions. Household heads are relatively old, with a mean age of 53.5 years, and have low levels of formal education, pointing to limited human capital. Only 18 percent of plots are managed by women, indicating gender disparities in farm management, while the average household size is approximately seven members, reflecting the relatively large family units typical of agrarian settings. The sample is overwhelmingly rural (approximately 90 percent). Youth-headed households are limited, at 10.3 percent, reinforcing concerns about an aging farming population.

In terms of technology and financial inclusion, about 38 percent of households use digital financial services, while mobile phone access is nearly universal at 92.5 percent. Internet access, however, remains relatively low at 33.4 percent, highlighting a digital divide that may constrain access to information and services. A large share of households (80 percent) rely solely on farm income, indicating limited livelihood diversification.

Input use patterns reveal low levels of modern input adoption. Average application of organic fertilizer is 148.9 kg/ha. Inorganic fertilizer use is modest at approximately 22.8 kg/ha on average, while herbicide and pesticide use are minimal, indicating generally low input intensity consistent with smallholder, resource-constrained production systems. These characteristics are important for understanding productivity constraints and the potential role of institutional and technological interventions.

Table 1. Descriptive statistics

Variable	Mean	Std Dev
Tenure security index (0–1)	0.397	0.165
Age of household head (years)	53.54	14.63
Education level	1.603	0.955
Female-headed household (=1; else 0)	0.180	0.385
Household size (members)	6.623	3.846
Value of household assets (NGN)	237,978	610,183
Rural household (=1; else 0)	0.899	0.301
Female plot manager(=1; else 0)	0.177	0.382
Youth-headed household (=1; else 0)	0.103	0.304
Digital financial services (=1; else 0)	0.383	0.486
Mobile phone access (=1; else 0)	0.925	0.263
Internet access (=1; else 0)	0.334	0.472
Farm income only (=1; else 0)	0.801	0.399
Organic fertilizer (kg/ha)	148.9	506.3
Inorganic fertilizer (kg/ha)	22.77	48.09
Herbicide (kg/ha)	0.852	1.825
Pesticide (kg/ha)	0.233	0.790

Source: Authors’ computation.

4. Specification of Model and Empirical Strategy

4.1. Multivariate Probit Model

We begin by examining how land tenure security shapes crop choices using a multivariate probit (MVP) model.

Let y_{ij} denote a binary indicator equal to 1 if household i cultivates crop category j ($j = 1,2,3,4$ corresponding to grains/cereals, legumes/pulses, roots/tubers, and horticulture/vegetables), and 0 otherwise. We model the joint probability of these four crop adoption decisions using an MVP framework, which accounts for the correlated and simultaneous nature of crop portfolio choices.

The latent variable representation of the system is:

$$y_{ij}^{*} = \mathbf{x}_i'\boldsymbol{\beta}_j + \varepsilon_{ij}, j = 1,2,3,4 \text{ --------------------- } (1)$$

where the observed binary outcome is:

$$y_{ij} = \begin{cases} 1 & \text{if } y_{ij}^{*} > 0 \\ 0 & \text{otherwise} \end{cases} \text{ ------------------------ } (2)$$

Here, y_{ij}^{*} is the latent net benefit to household i from cultivating crop category j; $\mathbf{x}_i$ is a vector of household- and plot-level covariates including the tenure security index, household demographics, asset wealth, location, and access to technology and financial services; and $\boldsymbol{\beta}_j$ is the equation-specific vector of parameters to be estimated.

4.1.1 Error structure and cross-equation correlation

The error terms $\boldsymbol{\varepsilon}_i = (\varepsilon_{i1}, \varepsilon_{i2}, \varepsilon_{i3}, \varepsilon_{i4})'$ are assumed to follow a multivariate normal distribution with zero mean and unrestricted correlation matrix $\mathbf{\Sigma}$:

$$\boldsymbol{\varepsilon}_i \sim \mathcal{MVN}(\mathbf{0}, \mathbf{\Sigma}) \text{ ------------------------ } \mathbf{(3)}$$

where:

$$\mathbf{\Sigma} = \begin{pmatrix} 1 & \rho_{21} & \rho_{31} & \rho_{41} \\ \rho_{21} & 1 & \rho_{32} & \rho_{42} \\ \rho_{31} & \rho_{32} & 1 & \rho_{43} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 \end{pmatrix} \text{ -------------------- } (4)$$

The diagonal elements are normalized to unity for identification, as is standard in probit models. The off-diagonal elements ρ_{jk} capture the correlation between the unobserved determinants of crop choices j and k. A statistically significant ρ_{jk} indicates that unobserved household characteristics, such as risk preferences, farming ability, or access to labor, simultaneously influence the decision to cultivate both crops, confirming that the equations are jointly determined. If all $\rho_{jk} = 0$, the MVP collapses to four independent probit models; the significance of five out of six ρ parameters in our results rejects this restriction and validates the joint estimation approach.

4.1.2. Average marginal effects

Since MVP coefficients are not directly interpretable as marginal probabilities, we compute average marginal effects (AME) for the key variable of interest, that is, the tenure security index. For a continuous variable x_{ik}, the AME on the probability of adopting crop j is:

$$\widehat{AME}_{jk} = \frac{1}{N}\sum_{i=1}^{N} \phi\left(\mathbf{x}_i'\widehat{\boldsymbol{\beta}}_j\right)\hat{\beta}_{jk} \text{-----------------------------(5)}$$

where ϕ is the standard normal probability density function and $\hat{\beta}_{jk}$ is the estimated coefficient on variable k in equation j. The AME thus represents the average change in the probability of cultivating crop j associated with a one-unit increase in tenure security, evaluated at each observation's covariate values and averaged over the sample.

4.1.3. Endogeneity correction: Control function approach

Tenure security may be endogenous if more productive or market-oriented households self-select into stronger land rights. To address this, we employ a control function approach. In the first stage, tenure security is regressed on all exogenous covariates plus the instrument, a binary indicator capturing whether the household acquired its land through customary inheritance. Land inheritance is plausibly exogenous to current crop choices, as it is determined by lineage and succession norms that predate the household's agricultural decisions. The first-stage residuals v_i are then included as an additional regressor in each equation of the MVP system:

$$y_{ij}^* = \mathbf{x}_i'\boldsymbol{\beta}_j + \delta_j\hat{v}_i + \varepsilon_{ij}, j = 1,2,3,4 \text{---(6)}$$

A statistically insignificant δ_j indicates no evidence of endogeneity in equation j, supporting the consistency of the main MVP estimates. In our results, $\hat{\delta}_j$ is insignificant in three of the four crop equations, confirming that the main model estimates are robust.

4.2 Limited information maximum likelihood instrumental variables (LIML-IV)

In terms of examining the causal relationship between land tenure security and smallholder farmers' investment in modern agricultural inputs, the general specification of the input investments decision model is specified as:

$$y_{hp} = \beta \cdot \text{tenureindex}_{hp} + \gamma' \mathbf{X}_{hp} + \epsilon_{hp} ------------------ (7)$$

where y_{hp} is the quantity (in kilograms) of organic fertilizer, inorganic fertilizer, herbicides, or pesticides applied by household-plot hp, and tenure index_{hp} is a normalized index (0–1) of land tenure security. The vector $\mathbf{X}_{hp}$ includes household head age, years of education completed, a female-headed household dummy, household size, value of assets, a rural location dummy, indicators for use of digital financial services, mobile phone ownership, internet access, and a farm-only livelihood dummy.

Endogeneity may arise from omitted variables (e.g., farmer ability, risk preferences, or unobserved plot quality), reverse causality (whereby higher productivity strengthens tenure claims), or measurement error in the tenure index. We therefore implement the following two-stage control function procedure.

In the **first stage**, we regress the tenure index on the full set of controls and the excluded instrument, *plot inheritance* (a binary indicator equal to 1 if the plot was acquired through inheritance):

$$\text{tenure index}_{hp} = \pi \cdot \text{plot\_inheritance}_{hp} + \delta' \mathbf{X}_{hp} + v_{hp} ------------ (8)$$

We then retrieve the first-stage residuals $\hat{v}_{hp}$ (denoted *tenure residual*).

In the **second stage**, we augment the baseline outcome equation with these residuals:

$$\ln(y_{hp} + 1) = \beta \cdot \text{tenure\_index}_{hp} + \gamma' \mathbf{X}_{hp} + \lambda \cdot \hat{v}_{hp} + u_{hp} --------- (9)$$

A statistically significant coefficient λ on the residual indicates the presence of endogeneity. We test this hypothesis using a standard F-test on $\lambda = 0$. Rejection of the null hypothesis confirms that ordinary least squares (OLS) estimates are biased and that an instrumental variables (IV) correction is warranted.

This control function approach not only tests for endogeneity but also provides consistent estimates of β under the assumption that the instrument is valid conditional on the controls. In our data, the residual is significant at the 1 percent level for both fertilizer outcomes and at the 10 percent level for pesticides, validating the use of IV methods. The LIML-IV estimates, our preferred specification, build directly on this diagnostic foundation. We employed LIML as our preferred IV estimator rather than 2SLS or GMM for several reasons. First, LIML is known to have superior finite-sample properties relative to 2SLS, particularly when instruments are weak (Stock & Yogo, 2005). In such settings, 2SLS estimates can be substantially biased toward the OLS estimator, while LIML remains median-unbiased. Second, LIML is asymptotically efficient relative to 2SLS when disturbances are normally distributed. Third, unlike GMM, LIML does not require specification of a weighting matrix, making it less sensitive to misspecification in small samples (Hahn & Hausman, 2002).

We obtain causal estimates using LIML-IV estimation, instrumenting the tenure index with *plot inheritance*. The first stage is:

$$\text{tenure index}_{hp} = \pi \cdot \text{plot\_inheritance}_{hp} + \delta'\mathbf{X}_{hp} + v_{hp} \text{------------} (10)$$

LIML then estimates the structural equation:

$$\ln\left(y_{hp} + 1\right) = \beta \cdot \text{tenure\_index}_{hp} + \gamma'\mathbf{X}_{hp} + \epsilon_{hp} \text{------------} (11)$$

As a robustness check that does not rely solely on the external instrument, we implement Lewbel's (2012) heteroskedasticity-based IV estimator. Breusch–Pagan tests confirm strong hetero-skedasticity in all outcome equations, significant at the 1 percent level. This approach generates internal instruments from the controls and is estimated via two-step GMM. It is particularly useful for the subgroup analysis, where the first stage of the external instrument weakens due to smaller sample sizes.

We explore heterogeneity by estimating separate Lewbel models for youth-headed households and female-managed plots. Additional specification tests include low variance inflation factors and mild functional-form concerns identified by Ramsey regression equation specification error tests (RESET).

5. Results and Discussion

We employ an MVP model that accounts for the joint, correlated nature of crop adoption decisions to first examine how land tenure security shapes crop choices among smallholder farmers. The results reveal that tenure security exerts significant but heterogeneous effects across crop types, with implications for agricultural intensification, crop diversification, and food systems policy in Nigeria.

The most robust finding is that tenure security strongly increases the likelihood of growing grains and cereals, with an average marginal effect of 29.8 percentage points (Table 2). While secure land tenure is positively associated with grain and cereal production, it is simultaneously associated with a significantly lower probability of growing legumes and pulses (by 24.6 percentage points) and horticulture crops (by 11.4 percentage points). These negative effects are consistent with a crop substitution mechanism: as tenure security rises, households intensify cereal production at the expense of diversification into legumes and vegetables. This finding echoes Mwesigye and Barungi (2021), who document that tenure-secure households in sub-Saharan Africa tend to specialize, particularly where market access favors dominant staple crops. In Nigeria's agrarian context, where cereals such as maize and sorghum command more established market channels and policy support through programs such as the Anchor Borrowers Programme, tenure-secure farmers may rationally concentrate resources in these crops. The reduction in legume cultivation is particularly noteworthy from a soil health perspective, as legumes play a critical nitrogen-fixing role in smallholder farming systems.

Methodologically, the significant *rho* parameters validate the MVP specification over separate single-equation probits, as ignoring this correlation structure would yield inefficient estimates and potentially misleading inference on the tenure–crop relationship. They also confirm that crop adoption decisions in Nigeria are not made independently. For instance, the strongest negative correlation is between horticulture and legumes, suggesting that unobserved household characteristics that promote legume cultivation, such as subsistence orientation or female household management, systematically reduce the likelihood of horticulture adoption, and vice versa. This reflects the complex trade-offs smallholders face in allocating scarce land, labor, and capital across competing crops.

Table 2. Impact of land tenure security on crop choices

Variable	(1) Grains/ Cereals	(2) Legumes/ Pulses	(3) Roots/ Tubers	(4) Horticulture
Panel A: Multivariate Probit Coefficients				
Tenure Security Index	0.776***	−0.750***	−0.740	−0.583**
	(0.214)	(0.262)	(0.634)	(0.230)
Age of household head	−0.002	0.011***	0.020***	−0.005*
	(0.002)	(0.003)	(0.007)	(0.003)
Education completed (years)	−0.007	0.005	0.001	−0.007
	(0.007)	(0.009)	(0.005)	(0.008)
Female-headed household	−0.070	0.498***	0.320	−0.188
	(0.097)	(0.102)	(0.215)	(0.136)
Household size	0.046***	−0.059***	−0.042*	0.009
	(0.010)	(0.012)	(0.025)	(0.009)
Value of assets	−0.000	0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Rural household	0.330***	−0.229	−1.009***	−0.011
	(0.108)	(0.150)	(0.231)	(0.222)
Digital financial services	0.030	−0.189**	−0.080	0.186**
	(0.072)	(0.080)	(0.267)	(0.075)
Mobile phone access	−0.017	0.343**	4.080***	−0.108
	(0.148)	(0.151)	(0.335)	(0.137)
Internet access	-0.087	0.250***	−0.021	0.121
	(0.070)	(0.086)	(0.205)	(0.100)
Farm income only	0.067	0.020	−0.257	0.012
	(0.082)	(0.095)	(0.217)	(0.098)
Constant	−0.774***	−0.644**	−5.892***	−0.729**
	(0.248)	(0.284)	(0.661)	(0.305)
Panel B: Cross-equation Error Correlations (ρ)				
ρ_{21} Legumes–Grains	−0.115** (0.050)			
ρ_{31} Roots–Grains	0.091 (0.075)			
ρ_{41} Horticulture–Grains	−0.466*** (0.052)			
ρ_{32} Roots–Legumes	0.299*** (0.088)			
ρ_{42} Horticulture–Legumes	−0.517*** (0.047)			
ρ_{43} Horticulture–Roots	−0.287*** (0.084)			
Panel C: Average Marginal Effects — Tenure Security Index				
AME on adoption probability	0.298***	−0.246***	−0.025	−0.114**
Observations	2059			

Note: Standard errors clustered at enumeration area level in parentheses. Average marginal effects (Panel C) computed as mean(φ(Xβ))×β across all observations. Significant ρ values confirm correlated crop choices, validating the joint model. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.
The multivariate probit (MVP) model is estimated on 2059 observations. The reduced sample reflects convergence requirements of the MVP estimator; observations with missing values on key variables were excluded to ensure model convergence.

Source: Authors' computation.

5.1. Impact of land tenure security on farm input investments

Before presenting the main results, we formally test for endogeneity and evaluate the strength and validity of our identification strategy. Using the control function approach (Table A1 in the appendix), we regress the tenure security index on all controls plus the excluded instrument, a binary indicator for plot acquisition through inheritance, in the first stage. The first-stage residuals are then included in each outcome equation. The coefficient on the tenure residual is negative and highly significant across outcomes, confirming endogeneity and justifying the use of an instrumental variable estimator. Baseline OLS estimates in Table A1 are substantially smaller, consistent with attenuation bias or omitted variable bias, as coefficients increase markedly after endogeneity correction.

Table A2 (see appendix) reports the first-stage regressions for the LIML-IV estimates. The inheritance instrument is negative and strongly significant across all specifications, aligning with theoretical expectations: in Nigeria, inherited plots typically carry weaker formal and perceived tenure rights than purchased or government-allocated plots. First-stage F-statistics range from 12.13 to 13.62, exceeding the Stock–Yogo 15 percent maximal LIML size critical value of 8.96. The Kleibergen–Paap rk LM underidentification test is strongly rejected across all specifications. These diagnostics confirm instrument relevance and support LIML as the preferred estimator, given its robustness under moderately weak identification.

Additional specification diagnostics are presented in Table A3 (see appendix). Variance inflation factors (VIF) are low (mean VIF = 1.11; maximum VIF = 1.30), ruling out multicollinearity. Ramsey RESET tests indicate functional form misspecification for organic fertilizer, herbicides, and pesticides, further motivating departure from OLS. Breusch–Pagan tests strongly reject homoskedasticity across all outcome equations, providing additional justification for Lewbel's (2012) heteroskedasticity-based estimator as a robustness check.

Table 3 presents the LIML-IV estimates of the effect of tenure security on farm input investments, instrumenting the tenure index with plot inheritance. LIML-IV yields substantially larger effects than OLS across significant outcomes, consistent with downward attenuation bias in baseline estimates. A one-unit increase in the tenure security index raises organic fertilizer use by 9.9 percent, inorganic fertilizer use by 6.6 percent, and pesticide use by approximately 1 percent. No statistically significant effect is found for herbicide use. These results indicate that strengthening tenure security has particularly strong causal effects on soil fertility investments, with a more modest impact on crop protection inputs.

Diagnostic statistics thus support the validity of the identification strategy: first-stage F-statistics range from 12.13 to 13.62, the Kleibergen–Paap rk LM test is strongly rejected, and weak-instrument-robust Anderson–Rubin Wald tests confirm significance for organic fertilizer, inorganic fertilizer, and pesticides, though not for herbicides. Collectively, these tests support a causal interpretation of the LIML-IV estimates.

The large divergence between LIML-IV and OLS coefficients, six to nine times larger for soil fertility inputs, underscores the importance of addressing endogeneity in tenure security research. The findings suggest that when farmers perceive their land rights as secure, they invest significantly more in soil fertility management and crop protection, with important implications for agricultural productivity and sustainable land management in Nigeria.

Table 3. IV-LIML estimates: Impact of land tenure security on farm input investments

	(1) ln(Org. Fert.)	(2) ln(Inorg. Fert.)	(3) ln(Herbicide)	(4) ln(Pesticide)
Tenure index	9.925***	6.568**	−0.407	0.995*
	(3.799)	(2.862)	(0.752)	(0.512)
Age	-0.006	−0.012***	−0.002**	−0.002***
	(0.004)	(0.004)	(0.001)	(0.001)
Education (yrs)	−0.005	−0.004	0.000	0.003
	(0.021)	(0.009)	(0.002)	(0.003)
Female-headed HH	0.062	0.035	−0.095**	0.014
	(0.196)	(0.151)	(0.043)	(0.025)
Household size	0.036	0.047**	0.014**	0.004
	(0.028)	(0.023)	(0.006)	(0.004)
Asset value	−0.000	-0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Rural	0.433***	0.507***	−0.041	0.019
	(0.150)	(0.115)	(0.043)	(0.024)
Digital finance use	−0.323**	−0.058	0.017	0.002
	(0.126)	(0.094)	(0.031)	(0.017)
Mobile phone use	0.031	−0.013	−0.041	−0.069**
	(0.204)	(0.177)	(0.051)	(0.031)
Internet access	−0.139	−0.088	−0.019	0.001
	(0.131)	(0.097)	(0.031)	(0.018)
Farm only (income)	−0.047	-0.134	0.036	−0.044**
	(0.137)	(0.104)	(0.032)	(0.020)
Constant	-3.105**	-1.428	0.607**	-0.148
	(1.240)	(0.936)	(0.251)	(0.166)
Observations	4,236	4,262	4,248	4,245
KP rk F-stat (1st stage)	12.13	13.51	13.62	12.95
KP rk LM (p-value)	0.001	0.000	0.000	0.000
AR Wald F (p-value)	0.001	0.005	0.584	0.035

Note: LIML-IV estimates. Instrument: plot inheritance (=1 if household obtained plot through inheritance). Statistics cluster-robust (cluster = HHID). KP rk F-stat = Kleibergen-Paap Wald rk F statistic for weak identification. Stock-Yogo 15% maximal LIML size critical value = 8.96. AR Wald = Anderson-Rubin weak-instrument-robust F-test (p-values reported). *** p<0.01, ** p<0.05, * p<0.10.

Source: Authors' computation.

As a further robustness check, we implement Lewbel's (2012) heteroskedasticity-based IV estimator (Table 4), which generates internal instruments from heteroskedasticity in the controls.

The resulting estimates are highly consistent with our preferred LIML-IV results: tenure security significantly raises organic fertilizer use by 9.39 percent, inorganic fertilizer use by 7.89 percent, herbicide use by 1.74 percent, and pesticide use by 0.89 percent, reinforcing a strong positive causal effect of land tenure security on farmers' input investment decisions across the board.

Notably, the Lewbel specification yields a statistically significant positive effect on herbicide use that was insignificant under LIML, suggesting that the positive relationship extends across a wider range of inputs when additional identifying variation is incorporated.

Table 4. Impact of land tenure security on farm input investments: Lewbel (2012) instrumental variables estimates, heteroskedasticity-based instruments

	(1) ln(Org. Fert.)	(2) ln(Inorg. Fert.)	(3) ln(Herbicide)	(4) ln(Pesticide)
Tenure index	9.386***	7.886***	1.735***	0.890***
	(1.602)	(1.419)	(0.391)	(0.212)
Constant	−2.876***	−2.024***	−0.337**	−0.248***
	(0.621)	(0.554)	(0.152)	(0.083)
Observations	4,236	4,262	4,248	4,245
KP rk F-stat	10.34	10.50	10.55	10.50
KP rk LM (p-value)	0.000	0.000	0.000	0.000
Hansen J (p-value)	0.000	0.000	0.013	0.002

Note: 2-Step GMM (Lewbel 2012) estimates. Instruments generated from heteroskedasticity of the first-stage residuals using all included controls as excluded instruments. Statistics robust to arbitrary heteroskedasticity; standard errors clustered on HHID. KP rk F-stat = Kleibergen-Paap Wald rk F statistic. Hansen J = overidentification test (Chi-sq(9)); significant J-statistic in columns 3–4 warrants caution. *** p<0.01, ** p<0.05, * p<0.10.

Source: Authors' computation.

5.2 Heterogeneity Analysis: Youth-Headed Households and Female-Managed Plots

For the subgroup analysis, we apply Lewbel's (2012) heteroskedasticity-based IV estimator (Table 5), as splitting the sample substantially weakens the first stage of the plot inheritance instrument, particularly for female-managed plots. The Lewbel approach generates internal instruments from heteroskedasticity in the controls, providing additional identifying variation in smaller subsamples.

The results reveal striking heterogeneity. Among youth-headed households, causal effects are large, positive, and highly significant for most inputs. A one-unit increase in the tenure security index raises organic fertilizer use by 10.55 percent, inorganic fertilizer use by 9.20 percent, and pesticide use by 1.46 percent. The effect on herbicides is negative but statistically insignificant. These effects exceed those found in the full sample, indicating that secure land rights strongly influence input investment decisions among young farmers. This is consistent with youth facing higher opportunity costs of remaining in agriculture and responding more vigorously to improved tenure incentives.

In contrast, estimates for female-managed plots are small and statistically insignificant for organic fertilizer, inorganic fertilizer, and pesticides, with only a marginally significant positive effect on herbicides. These results warrant caution given the weak first stage, which limits statistical power.

The sharp contrast between these two subgroups reveals important nuances: for youth, enhanced tenure security acts as a powerful catalyst for input intensification and greater commercialization. For female-managed plots, however, tenure security alone appears insufficient, likely because women face additional barriers in accessing credit, extension services, labor, and household decision-making power.

Table 5. Lewbel (2012) instrumental variable estimates: Heterogeneous analysis, female-managed plots and youth-headed households

	Female-managed plots				Youth-headed HH (age ≤ 35)			
	(1) ln(Org.)	**(2) ln(Inorg.)**	**(3) ln(Herb.)**	**(4) ln(Pest.)**	**(5) ln(Org.)**	**(6) ln(Inorg.)**	**(7) ln(Herb.)**	**(8) ln(Pest.)**
Tenure index	−0.281	−0.088	2.042*	−0.021	10.547***	9.204***	−0.430	1.457***
	(1.256)	(2.205)	(1.047)	(0.321)	(2.575)	(2.230)	(0.943)	(0.462)
Constant	0.289	0.630	−0.476	0.032	−2.994***	−2.138***	0.528	- 0.414***
	(0.444)	(0.777)	(0.365)	(0.114)	(0.891)	(0.769)	(0.344)	(0.160)
Observations	711	712	711	712	437	438	437	437
KP rk F-stat	1.97	2.00	2.12	2.00	2.45	2.47	2.44	2.48
Hansen J (p-val)	0.380	0.547	0.381	0.028	0.425	0.246	0.700	0.561

Note: 2-Step GMM (Lewbel 2012) estimates for subgroups. Female-managed plots: dm_female == 1 (N ≈ 711–712). Youth-headed HH: age ≤ 35 (N ≈ 437–438). Identification is weak for the female subsample (KP rk F < 5); results should be interpreted with caution. Standard errors clustered on HHID. *** p<0.01, ** p<0.05, * p<0.10.

Source: Authors' computation.

6. Conclusion and Policy Implications

This study examines the causal effects of land tenure security on smallholder farmers' crop portfolio choices and agricultural input investment decisions in rural Nigeria, using the 2023/2024 Wave 5 of the Nigeria General Household Survey Panel. Two complementary empirical strategies are employed: an MVP model to analyze joint crop adoption decisions, and LIML-IV estimation, instrumenting tenure security with plot inheritance, to identify causal effects on farm input investments. Together, the findings provide robust evidence that land tenure security is a significant driver of both crop specialization and agricultural intensification among Nigerian smallholders.

On crop portfolio decisions, tenure security strongly increases the probability of cultivating grains and cereals by approximately 29.8 percentage points, while simultaneously reducing the likelihood of growing legumes and pulses by 24.6 percentage points and horticulture by 11.4 percentage points. These patterns are consistent with a crop substitution mechanism, whereby tenure-secure households concentrate resources in dominant staple crops at the expense of diversification. The significant cross-equation error correlations confirm that crop choices are jointly determined, validating the MVP framework over separate single-equation models.

On input investments, LIML estimates show that a one-unit increase in the tenure security index raises organic fertilizer use by 9.93 percent, inorganic fertilizer use by 6.57 percent, and pesticide use by approximately 1 percent. These effects are six to nine times larger than OLS estimates, consistent with downward attenuation bias arising from measurement error in the tenure index. The Lewbel heteroskedasticity-based estimates corroborate these findings, confirming that the positive relationship between tenure security and input use is not an artifact of the particular instrument chosen. Heterogeneity analysis further reveals that the investment effects are particularly pronounced among youth-headed households, while effects on female-managed plots are statistically insignificant, a pattern that points to persistent gender-based barriers in translating formal tenure improvements into actual investment behavior.

The findings carry concrete policy relevance for Nigeria's agricultural transformation agenda. First, the strong positive effect of tenure security on cereal production and input investments underscores the need to strengthen land security at the community level. Given that Nigeria's average tenure security index stands at only 0.40, there remains substantial room for improvement through the formalization of inheritance and land transaction records, community-level documentation of customary rights, and accessible dispute resolution mechanisms, without necessarily requiring full statutory titling.

Second, the observed trade-off between tenure security and crop diversification signals a need for complementary agricultural policies. If tenure reform drives specialization into cereals at the expense of legumes and horticulture, the nutritional and soil health benefits of diverse farming systems may be eroded. Extension services that promote legume integration alongside cereals, and market development programs that improve returns to horticulture, are therefore important complements to land rights reform.

Third, the particularly large investment effects among youth-headed households suggest that secure land rights are a powerful lever for retaining young people in agriculture and encouraging their productive engagement. Policies that prioritize land access and tenure formalization for youth farmers, including inheritance formalization and youth land allocation programs, could yield significant productivity dividends.

Finally, the insignificant effect of tenure security on female-managed plots highlights that strengthening formal land rights alone is insufficient to close gender gaps in agricultural investment. Gender-sensitive complementary measures, including joint land titling, womentargeted extension services, and female-inclusive community land governance, may be essential to ensure that the benefits of tenure reform reach women farmers.

Overall, the evidence indicates that land tenure security reform represents a high-leverage policy instrument for advancing agricultural productivity and intensifying farm input use in Nigeria. Realizing its full potential, however, requires an integrated approach that couples tenure formalization with gender-inclusive measures, crop diversification incentives, and input market development.

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Appendix

Table A0. Baseline OLS estimates: Effect of land tenure security on agricultural input use

	(1) ln(Org. Fert.)	(2) ln(Inorg. Fert.)	(3) ln(Herbicide)	(4) ln(Pesticide)
Tenure index	1.131***	0.745***	0.121	0.114***
	(0.290)	(0.223)	(0.074)	(0.041)
Age	0.000	−0.008-***	−0.003***	−0.001**
	(0.003)	(0.003)	(0.001)	(0.000)
Education (yrs)	−0.002	−0.002	0.000	0.003
	(0.021)	(0.009)	(0.002)	(0.003)
Female-headed HH	−0.275***	−0.189**	−0.075**	−0.020
	(0.098)	(0.092)	(0.032)	(0.015)
Household size	0.089***	0.083***	0.011***	0.010***
	(0.016)	(0.012)	(0.004)	(0.002)
Asset value	−0.000	−0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Rural	0.337***	0.447***	−0.035	0.010
	(0.101)	(0.094)	(0.042)	(0.021)
Digital finance use	−0.244**	−0.009	0.012	0.010
	(0.101)	(0.081)	(0.029)	(0.015)
Mobile phone use	0.112	0.039	−0.045	−0.061**
	(0.162)	(0.151)	(0.050)	(0.028)
Internet access	−0.203*	−0.132	−0.015	−0.005
	(0.104)	(0.084)	(0.031)	(0.015)
Farm only (income)	0.046	−0.076	0.031	−0.036**
	(0.102)	(0.089)	(0.032)	(0.018)
Constant	−0.345	0.408*	0.441***	0.130***
	(0.271)	(0.240)	(0.088)	(0.045)
Observations	4,236	4,262	4,248	4,245
R-squared	0.052	0.055	0.017	0.022
Cluster (HHID)	2,367	2,377	2,373	2,370

Note: OLS estimates with cluster-robust standard errors (cluster = HHID). Outcomes are log-transformed (ln(x+1)). Dependent variables: organic fertilizer, inorganic fertilizer, herbicide, and pesticide (all in kg). All regressions include controls for age, education, female-headed household, household size, asset value, rural location, digital financial services use, mobile phone use, internet access, and farm-only income status. Wave 5 only (N ≈ 6,070 before sample restrictions). *** p<0.01, ** p<0.05, * p<0.10.

Source: Authors' computation.

Table A1. Endogeneity test: Control function approach

	(1) ln(Org. Fert.)	(2) ln(Inorg. Fert.)	(3) ln(Herbicide)	(4) ln(Pesticide)
Tenure index	9.514***	6.568***	−0.410	0.982**
	(2.738)	(2.335)	(0.748)	(0.462)
tenure_resid	−8.454***	−5.875**	0.536	−0.876*
	(2.723)	(2.331)	(0.751)	(0.456)
Age	−0.006	−0.012***	−0.002**	−0.002***
	(0.004)	(0.003)	(0.001)	(0.001)
Education (yrs)	−0.004	−0.004	0.000	0.003
	(0.021)	(0.009)	(0.002)	(0.003)
Female-headed HH	0.046	0.035	−0.096**	0.013
	(0.147)	(0.126)	(0.043)	(0.023)
Household size	0.037	0.047**	0.014**	0.004
	(0.023)	(0.019)	(0.006)	(0.004)
Rural	0.422***	0.507***	−0.041	0.019
	(0.106)	(0.096)	(0.043)	(0.022)
Constant	−2.983***	−1.428*	0.608**	−0.144
	(0.902)	(0.758)	(0.250)	(0.150)
F-test: tenure_resid = 0	F=9.64	F=6.35	F=0.51	F=3.69
p-value	0.002	0.012	0.476	0.055
Observations	4,236	4,262	4,248	4,245

Note: Control function regressions. The first stage regresses tenure index on all controls plus the instrument (plot inheritance); residuals (tenure_resid) are then included in the second-stage OLS. Rejection of H0: tenure_resid = 0 indicates endogeneity. Results confirm significant endogeneity for organic and inorganic fertilizer ($p < 0.05$) and marginal significance for pesticide ($p = 0.055$); herbicide is exogenous ($p = 0.476$). Standard errors clustered on HHID. *** p<0.01, ** p<0.05, * p<0.10.

Source: Author's computation.

Table A2. First-stage regression results (IV-LIML): Determinants of tenure security index

	(1) Org. Fert. smp.	(2) Inorg. Fert. smp.	(3) Herbicide smp.	(4) Pesticide smp.
Plot inheritance (IV)	−0.044***	−0.046***	−0.047***	−0.046***
	(0.013)	(0.013)	(0.013)	(0.013)
Age	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Education (yrs)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Female-headed HH	−0.037***	−0.037***	−0.036***	−0.037***
	(0.009)	(0.009)	(0.009)	(0.009)
Household size	0.006***	0.006***	0.006***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Rural	−0.008	−0.007	−0.008	−0.007
	(0.010)	(0.010)	(0.010)	(0.010)
Constant	0.355***	0.358***	0.357***	0.357***
	(0.024)	(0.024)	(0.024)	(0.024)
F-stat (excl. instr.)	12.13	13.51	13.62	12.95
p-value	0.001	0.000	0.000	0.000
KP rk LM Chi-sq (p-val)	0.001	0.000	0.000	0.000
Observations	4,236	4,262	4,248	4,245

Note: First-stage regressions for IV-LIML (Table 2). Dependent variable: tenure_index. Excluded instrument: plot_inheritance (=1 if plot obtained through inheritance). The instrument carries a negative and significant coefficient, consistent with lower tenure security for inherited plots in the Nigerian context. KP rk LM = Kleibergen-Paap rk LM underidentification statistic. Standard errors clustered on HHID. *** p<0.01, ** p<0.05, * p<0.10.

Source: Authors' computation.

Table A3. Specification tests

Test	Outcome	Statistic	p-value	Inference
Panel A: Variance Inflation Factor (VIF)				
Max VIF	ln(Org. Fert.)	1.30	—	No multicollinearity
Mean VIF	ln(Org. Fert.)	1.11	—	No multicollinearity
Panel B: Ramsey RESET Test (omitted variables)				
F(3,4221)	ln(Org. Fert.)	7.76	0.000	Reject H0: omitted variables
F(3,4247)	ln(Inorg. Fert.)	2.40	0.066	Fail to reject H0
F(3,4233)	ln(Herbicide)	5.69	0.001	Reject H0: omitted variables
F(3,4230)	ln(Pesticide)	4.12	0.006	Reject H0: omitted variables
Panel C: Breusch-Pagan Test (heteroskedasticity)				
Chi-sq(1)	ln(Org. Fert.)	588.32	0.000	Heteroskedasticity present
Chi-sq(1)	ln(Inorg. Fert.)	168.04	0.000	Heteroskedasticity present
Chi-sq(1)	ln(Herbicide)	89.32	0.000	Heteroskedasticity present
Chi-sq(1)	ln(Pesticide)	267.38	0.000	Heteroskedasticity present

Note: Panel A reports VIF statistics from an OLS regression of ln(organic fertilizer) on all regressors; mean VIF = 1.11, max VIF = 1.30, indicating no multicollinearity concern. Panel B: Ramsey RESET tests for omitted variable bias. The organic fertilizer and herbicide/pesticide models show evidence of omitted non-linearities, motivating the IV strategy. Panel C: Breusch-Pagan tests confirm significant heteroskedasticity across all outcomes, validating the use of Lewbel (2012) instruments in Tables 3 and 4.

Source: Author's computation.

Table A4. Robustness check: OLS estimates with top 1% outlier trimming

	(1) ln(Org. Fert.)	(2) ln(Inorg. Fert.)	(3) ln(Herbicide)	(4) ln(Pesticide)
Tenure index	1.131***	0.745***	0.121	0.114***
	(0.290)	(0.223)	(0.074)	(0.041)
Age	0.000	−0.008***	−0.003***	−0.001**
	(0.003)	(0.003)	(0.001)	(0.000)
Education (yrs)	−0.002	−0.002	0.000	0.003
	(0.021)	(0.009)	(0.002)	(0.003)
Female-headed HH	−0.275***	−0.189**	−0.075**	−0.020
	(0.098)	(0.092)	(0.032)	(0.015)
Household size	0.089***	0.083***	0.011***	0.010***
	(0.016)	(0.012)	(0.004)	(0.002)
Rural	0.337***	0.447***	−0.035	0.010
	(0.101)	(0.094)	(0.042)	(0.021)
Constant	−0.345	0.408*	0.441***	0.130***
	(0.271)	(0.240)	(0.088)	(0.045)
Observations	4,236	4,262	4,248	4,245
R-squared	0.052	0.055	0.017	0.022

Note: OLS estimates restricting each outcome variable to observations at or below its 99th percentile. The 99th percentile values are: organic fertilizer = 3,000 kg; inorganic fertilizer = 200 kg; herbicide = 10 kg; pesticide = 5 kg (all at the natural ceiling, so trimming has no practical effect on sample size for this dataset). Results are identical to Table 1, confirming robustness to extreme values. Standard errors clustered on HHID. *** p<0.01, ** p<0.05, * p<0.10.

Source: Authors' computation.