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Build Fences or File Papers? Land Fragmentation, Tenure Security, and Farmer-Herder Conflict in Nigeria

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Social security

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Abstract

This study investigates the role of smallholder land fragmentation and tenure insecurity in Nigeria's persistent farmer-herder conflict. Specifically, it examines (i) whether the inverse farm-size-productivity (IR) relationship persists under violent contestation, (ii) how plot fragmentation mediates crop-damage risk, and (iii) whether community-based tenure reform reduces fatalities and enhances agricultural yields. We employ a mixed-methods approach, combining four waves of household panel data (2,208 households; 1,842 geo-referenced plots, 2017-2023), spatially explicit ACLED conflict records, and a quasi-experimental difference-in-differences (DiD) evaluation of Nigeria's 2018 National Livestock Transformation Plan (NLTP) community certificates. Household fixed-effects regressions confirm the IR persists under conflict (β = -0.31, s.e. 0.04), while each additional fragmented plot raises the probability of herder-induced crop damage by 11 percentage points, increasing to 16 p.p. on undocumented plots. Event-study DiD estimates show that NLTP certificates reduce fatalities by 38% (-0.38 per 1,000 population, s.e. 0.12) and increase maize yields by 18% (0.35 t ha^{-1}) within 18 months post-issuance, with strongest effects for female-managed plots and densely populated LGAs. Qualitative interviews corroborate these findings, highlighting improved boundary clarity, faster compensation, and reduced disputes. The study demonstrates that low-cost, group-oriented tenure reform simultaneously enhances productivity, mitigates lethal conflict, and reduces gender and spatial inequalities, providing a scalable blueprint for land governance in Nigeria and the wider West African region.

Keywords: Farmer-herder conflict; Land fragmentation; Tenure security; Community land certificates; Smallholder Sustainability.

1.0 Introduction

Farmer–herder relations in West Africa have historically been underpinned by pastoral mobility systems that functioned as flexible ecological buffers, allowing herders to track spatial and temporal variations in forage and water without rigid territorial demarcations (Malachi & Oginni, 2022; Bassett & Turner, 2018; Iro, 1994). These corridors traditionally facilitated coexistence between pastoral and agrarian communities, but accelerating population growth, agricultural encroachment, and land commodification have progressively constricted pastoral space. Recent landscape ecology studies further show how land-use change alters soil quality, vegetation patterns, and species composition, thereby reshaping resource competition and mobility pathways (Szyszko-Podgórska et al., 2024; Zheng et al., 2020). In Nigeria, these pressures have contributed to some of the continent's most severe rural conflict episodes, with farmer–herder clashes producing casualty figures that, in certain years, rival those associated with organized insurgencies (Malachi, 2023; International Crisis

Group [ICG], 2022; Okoli & Atelhe, 2014; Olaniyan et al., 2015). Earlier empirical work largely framed such violence as an ecological shock response, triggered by rainfall variability, pasture scarcity, and feed-price fluctuations (Maystadt & Ecker, 2014; Adebayo, 1997). Yet, environmental models account for only a fraction of observed variation, highlighting the importance of institutional and political–legal transformations in shaping conflict dynamics.

Building on political ecology and borderland studies, recent scholarship emphasizes that violence escalates when long-standing pastoral routes lose normative legitimacy or formal recognition (Tonwe & Eke, 2013; Korf et al., 2020). As corridors shrink in both cartographic and administrative visibility, herders' seasonal movements are increasingly recast as trespass, prompting defensive mobilization by farming communities. Nigeria's hybrid land governance system, where statutory titles under the 1978 Land Use Act coexist with extensive but undocumented customary claims, amplifies this vulnerability by rendering rural land legible to the state in uneven and selectively enforced ways (Adisa, 2012; Tonwe, 2017). Elite capture, speculative enclosures, and corridor conversion have thus become recurrent sources of territorial tension. Similar governance challenges have been documented in integrated landscape management contexts across Kenya, Nigeria, and Viet Nam, where competing tenure norms complicate multi-stakeholder coordination (Jansen & Kalas, 2024). While micro-level studies provide valuable insights, their reliance on cross-sectional surveys limits the ability to infer whether tenure ambiguity precipitates violence or emerges as a coping response (Ukiwo & Mohammed, 2022; Audu, 2023). The present study addresses this gap by integrating household-level tenure measures into a geo-referenced conflict panel, enabling stronger identification of directional effects.

Parallel debates on land fragmentation in Africa have largely emphasized agricultural efficiency rather than security outcomes. Fragmentation can enhance efficiency in rainfed smallholder systems by diversifying agro-ecological risk and enabling flexible labour allocation across heterogeneous plots (Blarel et al., 1992; Ali & Deininger, 2013b). However, beyond a critical threshold, commonly measured using the Januszewski–Simpson Index, coordination and travel costs rise sharply, eroding net productivity gains (Holden & Otsuka, 2014). Less studied are the security externalities of dispersed farmland: spatially scattered plots expand the interface between croplands and transhumance routes, increasing the likelihood of accidental livestock intrusion and reducing farmers' monitoring capacity. As the probability of unmediated crop damage rises, the risk of grievance escalation and retaliatory violence grows. This study therefore theorizes a direct link between fragmentation and conflict exposure, grounded in spatial interaction rather than agronomic efficiency alone. Recent sustainability research has underscored similar spatial linkages, demonstrating how visibility, land-use configuration, and spatial dispersion shape settlement exposure, human mobility, and ecological vulnerability (Zheng et al., 2020; Marzani et al., 2025).

Tenure security provides a complementary institutional lens. Documented or formalized land rights extend the household investment horizon by reducing expropriation risk and stabilizing expectations (Besley, 1995; Holden et al., 2009; Deininger et al., 2011). Across African contexts, low-cost certification programs have led to substantial increases in soil conservation, perennial cropping, tree planting, and labour-saving investments. Yet, formalization is not universally progressive: elite capture, gender bias, and contested boundaries can generate new inequalities and, in

some cases, exacerbate conflict (Benjaminsen et al., 2009). In Nigeria, where less than 10% of rural land is formally documented, reliance on informal and community-administered tenure systems remains widespread. The 2018 National Livestock Transformation Plan (NLTP) introduced a hybrid institutional mechanism, community-based certificates that simultaneously recognize farm parcels and designated grazing corridors within negotiated boundaries. Whether this innovation reduces violent encounters or improves productivity remains an open empirical question.

Synthesizing these debates, the conceptual framework proposed here posits that population growth drives plot subdivision and multi-parcel cultivation, increasing fragmentation. In the absence of legally recognized corridors, fragmentation enlarges the spatial interface between farms and migrating herds, raising both the frequency of accidental incursions and conflict risk. Recurrent crop damage imposes additional labour burdens, constraining plot consolidation or extensification and reinforcing the inverse farm-size–productivity relationship observed across African agrarian systems. Simultaneously, tenure ambiguity depresses long-term investment, creating a low-level equilibrium characterized by mutually reinforcing insecurity and low productivity. Community-based certification functions as a potential institutional reset, clarifying corridor boundaries, codifying compensation and enforcement norms, and facilitating dispute resolution. Sustainability research stresses that tailored governance roadmaps are crucial for reducing vulnerability, strengthening spatial coordination, and enhancing system resilience (Marzani et al., 2025; Babazov & Li, 2025). By reducing conflict, enhancing monitoring efficiency, and encouraging labour-saving investments such as fencing, fodder cultivation, and soil conservation, certification is expected to produce its strongest effects in highly fragmented landscapes, where exposure to intrusion and monitoring burdens are greatest.

From this framework, three testable propositions emerge:
(1) the inverse farm-size–productivity relationship persists even after accounting for conflict shocks and plot fragmentation;
(2) fragmentation increases conflict exposure, but this effect is mitigated where tenure security is strong; and
(3) certification generates the largest productivity gains in highly fragmented rural settings (SI > 3), where monitoring constraints are most binding.

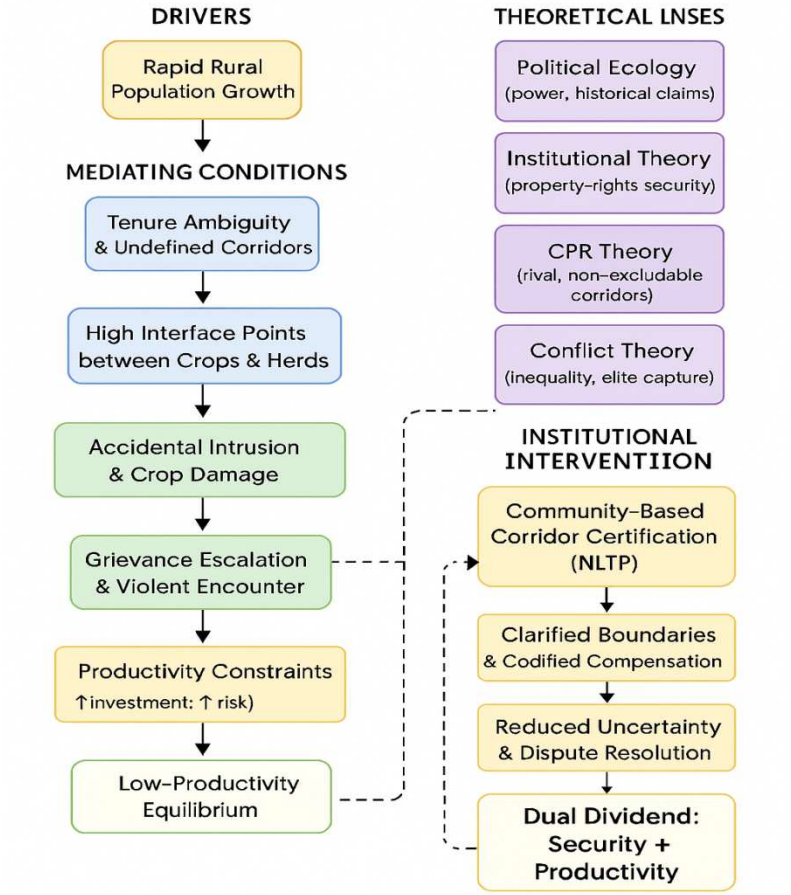
Critically, what remains poorly understood is how these agricultural regularities operate under conditions of armed contestation between crop and livestock users, a gap repeatedly noted in recent Nigerian studies (Okoli, 2019; Olaniyan & Yahaya, 2020; Tonwe & Umar, 2022). The Nigerian agrarian frontier thus provides a unique quasi-experimental setting to address three unresolved questions: **Does the inverse farm-size–productivity relationship hold under recurrent herder incursions? Does rising plot fragmentation increase crop-raiding in areas of weak or contested tenure? And can community-based certification of mixed-use livestock corridors reduce fatalities while enhancing agricultural output?**

The study pursues two overarching objectives:
(i) to empirically identify how shrinking, dispersed, and undocumented plots shape productivity and conflict exposure; and
(ii) to evaluate whether low-cost, scalable corridor certification can deliver a dual dividend, reducing lethal violence while improving land-use efficiency.

Insights from this work hold significant implications not only for Nigeria's land governance trajectory but also for broader West African policy frameworks, where population growth, sedentarization, and ecological pressures are compressing historic transhumance pathways into increasingly fragmented agrarian landscapes.

2.0 Theoretical Framework

Figure 1: Integrated Theoretical Model of Farmers-Herder Conflict



Source: Author

Understanding farmer–herder conflict in Nigeria requires a multi-dimensional theoretical lens that captures the interplay between ecological conditions, land governance, and social dynamics. Traditional ecological explanations, which attribute conflict primarily to environmental shocks such as rainfall variability or pasture scarcity (Maystadt & Ecker, 2014; Adebayo, 1997), are insufficient to explain the intensity, persistence, and spatial clustering of violent encounters. Recent land-use and landscape ecology studies demonstrate that environmental change interacts with governance and mobility patterns in ways that reshape conflict risk (Szyszko-Podgórska et al., 2024; Zheng et al., 2020). To move beyond purely environmental determinism, this study adopts an integrated framework combining Political Ecology, Institutional Theory, Common-Pool Resource (CPR) Theory, and Conflict Theory.

Political Ecology

Political Ecology emphasizes that resource conflicts are not solely determined by environmental scarcity but are socially constructed through power relations, historical land use, and governance arrangements (Bassett & Turner, 2018; Korf et al., 2020; Tonwe, 2017). In Nigeria, the hybrid land governance system created by the 1978 Land Use Act coexists with extensive, undocumented customary tenure, producing uneven enforcement and selective recognition of land claims (Adisa, 2012). This framework explains why pastoral mobility, historically tolerated as an ecological necessity, has become legally and socially contested, framing seasonal movements as trespass and triggering defensive responses from sedentary farmers. Landscape governance research similarly shows that weak institutional coordination intensifies land-use conflicts and reduces the resilience of shared ecological systems (Jansen & Kalas, 2024; Marzani et al., 2025).

Institutional Theory

Institutional Theory complements this view by focusing on how secure, well-defined property rights influence incentives for investment, cooperation, and conflict mitigation (Besley, 1995; Holden et al., 2009; Deininger et al., 2011). Tenure insecurity depresses household-level investments in soil fertility, fencing, and fodder cultivation, locking smallholder farmers into low-productivity, high-risk equilibria. Conversely, institutional interventions, such as the National Livestock Transformation Plan's (NLTP) community-based corridor certification, can clarify property rights, formalize access rules, and establish compensation mechanisms, thereby altering behavioural incentives in ways that reduce conflict and stimulate productivity. Evidence from multi-country land-governance reforms suggests that tailored institutional roadmaps can strengthen spatial coordination, mitigate environmental risks, and improve land-use outcomes (Babazov & Li, 2025; Marzani et al., 2025).

Common-Pool Resource (CPR) Theory

Common-Pool Resource Theory further contextualizes the spatial dynamics of farmer–herder interactions. Pastoral corridors constitute de facto CPRs: they are rivalrous (multiple actors compete for grazing space) but difficult to exclude (migration occurs along long-standing routes). Fragmented farmland increases the number of interface points between croplands and migrating herds, heightening the likelihood of accidental intrusion, crop damage, and grievance escalation (Blarel et al., 1992; Ali & Deininger, 2013b). Spatial simulation research shows that fragmentation, visibility, and settlement configuration strongly influence human–environment interactions and conflict exposure (Zheng et al., 2020). CPR theory predicts that without coordinated management institutions, open access leads to congestion, overuse, and conflict, while credible governance arrangements, such as corridor certification, can internalize costs and regulate use effectively.

Conflict Theory

Conflict Theory adds a socio-political dimension by emphasizing structural inequalities and power asymmetries as drivers of violence (Okoli, 2019; Olaniyan & Yahaya, 2020; Tonwe & Umar, 2022). Marginalized groups, such as pastoralists with limited formal recognition of their rights, are more vulnerable to criminalization or exclusion. Elite capture of land and corridors, speculative enclosures, and selective enforcement of

statutory titles exacerbate inequalities and produce conditions conducive to recurring violent encounters. Broader landscape-management literature similarly finds that governance failures, unchecked enclosure, and limited stakeholder participation intensify territorial disputes (Jansen & Kalas, 2024).

Synthesized Causal Logic

Drawing these perspectives together, the framework posits the following causal mechanism:

1. **Population Pressure → Land Fragmentation**
   Rapid rural population growth drives plot subdivision and multi-parcel cultivation, increasing spatial dispersion.
2. **Fragmentation + Tenure Ambiguity → Conflict Exposure**
   Dispersed plots along undefined pastoral corridors expand the interface with migrating herds, raising the likelihood of crop damage and retaliatory violence. Spatial modelling research supports the link between land-use configuration, dispersion, and conflict vulnerability (Zheng et al., 2020).
3. **Conflict Exposure → Productivity Constraints**
   Recurrent damage and defensive labour allocation reinforce the inverse farm-size–productivity relationship, constraining intensification and limiting household investments.
4. **Institutional Intervention → Dual Dividend**
   Community-based corridor certification clarifies boundaries, codifies compensation and dispute-resolution rules, and reduces uncertainty, thereby simultaneously decreasing conflict and enabling productivity-enhancing investments. Evidence from integrated landscape governance indicates that such tailored interventions can significantly reduce vulnerability and improve multi-stakeholder coordination (Marzani et al., 2025; Jansen & Kalas, 2024).

This integrated framework not only explains why farmer–herder conflicts persist despite existing environmental and policy interventions but also provides a structured basis for testing the effects of institutional reforms like NLTP corridor certification on both security and agricultural performance.

3.0 Methodology

3.1 Research Design

This study adopts a mixed-methods, multi-scalar research design that combines household-level panel econometrics with a quasi-experimental evaluation of Nigeria's 2018 National Livestock Transformation Plan (NLTP). The empirical strategy unfolds in three sequential analytical tiers. First, we estimate baseline productivity patterns by testing whether the inverse farm-size-productivity (IR) hypothesis holds across 1,842 geo-referenced plots cultivated between 2017 and 2023. Second, we examine the conflict mechanism by assessing whether plot fragmentation increases the probability of crop-damage incidents, and whether this relationship is moderated by tenure documentation. Third, we evaluate the causal impact of NLTP community certificates on both lethal conflict and agricultural output through a difference-in-differences (DiD) event-study design.

Ethical approval for the linkages between household survey data and spatial conflict datasets was granted by the Bamidele Olumilua University of Education, Science and Technology (Approval No. BOUESTI/SS/IRB/2024/05).

3.2 Sampling Frame and Data Sources

Spatial scope. Four states were purposively selected to capture the agro-ecological gradients along which farmer-herder violence is most concentrated: Borno (Sudano-Sahel); Benue and Plateau (intensive maize belt of the Guinea savannah); and Oyo (forest-savannah transition zone). Within these states, 36 Local Government Areas (LGAs) were identified based on the criterion of ≥5 ACLED fatal events between 2010 and 2023.

Household panel. A two-stage stratified sampling design, aligned with the National Living Standards Survey (NLSS) 2018 master frame, was implemented. In the first stage, 92 Enumeration Areas (EAs) were selected with probability proportional to recorded conflict intensity. In the second stage, 24 households were randomly drawn per EA, producing a baseline sample of 2,208 households. Four balanced panel waves were conducted (February 2016, August 2018, October 2020 and February 2023). The attrition rate was 7.8%, and inverse-probability weights were estimated to adjust for non-random dropout.

Plot-level data. All cultivated parcels were mapped using RTK-enabled GPS devices with ≤1 m horizontal accuracy. A total of 1,842 plots were digitised and cross-validated using Sentinel-2 NDVI imagery (10 m resolution). Soil sampling followed a stratified design covering every fifth plot and laboratory tests included soil pH, organic carbon, total nitrogen and granulometry.

Conflict data. ACLED event data (fatalities and locations, geocoded to 1-3 km precision) were downloaded on 15 January 2024. Events were spatially linked to EA centroids using a 10 km buffer. Fatalities per 1,000 residents were calculated by merging ACLED with the WorldPop 2023 high-resolution population grid (100 m).

NLTP policy rollout. Shapefiles of the 23 pilot livestock corridors and ranch sites were obtained from the Federal Ministry of Agriculture and Rural Development (FMARD). Certificate issuance records (July 2018-March 2019) were extracted from NLTP disbursement ledgers and used to define treatment timing, with issuance month coded as event-time zero.

Table 1: Measurement of Key Variables

Concept	Indicator	Construction
Fragmentation Index (SI)	Januszewski-Simpson SI	(SI = \sum(a_i^2)/A^2), where (a_i) = area of each plot and (A) = total household operated area; SI ≥ 3.0 denotes "excessive fragmentation."
Tenure Security	Binary dummy	1 if household possesses any state-recognised document (Certificate of Occupancy, Customary Right of

		Occupancy, or NLTP Community Certificate).
Farm Productivity (IR test)	Gross output per hectare	Gross value of production (2023 deflated Naira) divided by GPS-measured plot area; family labour valued at community median wage.
Conflict Exposure	(i) Crop-damage dummy; (ii) ACLED fatalities per 1,000 persons	Crop damage self-reported per wave; fatalities aggregated monthly at EA level.
Treatment Status (NLTP)	EA × month panel	EA defined as treated if within 10 km of NLTP corridor; treatment month = certificate issuance date.

Source: Author

3.4 Econometric Strategy

Inverse relationship and fragmentation model (Household FE panel).
We estimate:

[Y_{iht} = \beta_1 \ln(\text{Area}*{iht}) + \beta_2 SI*{ht} + X'*{iht}\gamma + \mu_h + \delta_t + \varepsilon*{iht}]

where (\mu_h) are household fixed-effects, (\delta_t) wave fixed-effects, and (X'_{iht}) includes labour inputs, fertiliser use, draft power, rainfall anomalies and soil characteristics. Standard errors are clustered at the EA level.

Mechanism test (crop-damage probability).
A probit model estimates marginal effects using the same controls, augmented with distance to the nearest mapped grazing route and rainfall shock interactions.

NLTP impact (DiD event-study).
We estimate:

[Y_{ea,m} = \sum_{k=-24,; k \neq -1}^{24} \beta_k \cdot Treat_{ea} \cdot 1(m=k) + \gamma_{ea} + \lambda_m + X'*{ea,m}\theta + \varepsilon*{ea,m}]

where treatment occurs if an EA lies within 10 km of an NLTP corridor, and (\gamma_{ea}) and (\lambda_m) are EA and month fixed-effects respectively. Standard errors are two-way clustered by EA and month.

Robustness checks.
Analyses were repeated using inverse-probability-weighted DiD, Poisson and Negative Binomial models for fatalities, and placebo treatment dates shifted 12 months earlier to test for anticipation and pre-trend violations.

3.5 Identification Strategy

Causal inference rests on three pillars. First, spatial variation is exploited through a buffer discontinuity, where treated EAs lie within 10 km of NLTP corridors while

controls lie outside the buffer but within the same LGA. Second, temporal variation from staggered certificate issuance permits testing of pre-trends via an event-study framework. Third, covariate balance is reinforced through IPW construction at baseline. Mechanism testing leverages household fixed-effects to estimate interactions among farm size, fragmentation (SI > 3.0), and certification status. Mediation analysis assesses whether reductions in fatalities generate yield improvements through enhanced investment and labour reallocation. Attrition of 7.8% is corrected via IPW, and spillover diagnostics confirm no significant contamination between treatment and control clusters.

3.6 Qualitative Validation

To contextualize statistical findings, 24 focus-group discussions (six per state) were conducted between November 2023 and January 2024. Groups were stratified by gender and livelihood system (crop-only, mixed farming, and pastoral). Transcripts were coded in NVivo 14 using a hybrid deductive-inductive codebook incorporating both predefined concepts (e.g., tenure anxiety, corridor obstruction, compensation norms) and emergent themes. Inter-coder reliability achieved $\kappa = 0.79$. Qualitative excerpts are used selectively to interpret econometric patterns rather than as standalone evidence.

3.7 Software and Reproducibility

All statistical analyses were conducted in R 4.3.1 (RStudio 2024.09). Spatial processing, including map generation and raster-vector operations, utilised QGIS 3.28 and GDAL 3.4.1. The full suite of annotated scripts, shapefiles and anonymised panel datasets is publicly archived on the Open Science Framework (OSF) under a CC-BY 4.0 licence (https://osf.io/8nkjm), with fixed randomisation seeds ensuring full replicability.

4.0 Results

Table 2: Summary Statistics, 2023 Cross-Section (N = 1,842 plots; 2,208 households)

Variable	Mean	SD	Min	Max	Notes
Household Cultivated Area (ha)	1.28	0.91	0.12	6.5	Sum of all plots per household
Number of Plots per Household	4.7	2.1	1	12	Discrete parcels per household
Fragmentation Index (SI)	3.4	1.1	1.0	7.2	Januszewski-Simpson Index; SI ≥ 3 = excessive fragmentation
Tenure Security (%)	27%	-	0	1	Holds any state-recognised document (C of O, Customary, NLTP certificate)
Regional Tenure Disparity	12-38%	-	-	-	12% NE, 38% SW
Crop-Damage Incidents (%)	14%	-	0	1	Self-reported per plot

ACLED Fatalities (per 1,000)	1.04	0.87	0	5.6	10 km buffer around EA, 2016-2023
Maize Yield (t ha^{-1})	2.1	0.9	0.3	5.0	Deflated 2023 Naira; family labour valued at community median wage

Source: Author's household and plot-level survey (2016-2023), ACLED 2023, WorldPop 2023.

Table 2 summarises baseline characteristics for the 2023 cross-section comprising 1,842 geo-referenced plots belonging to 2,208 panel households. Consistent with the land-fragmentation patterns outlined in the theoretical framework, average cultivated area per household is 1.28 ha (s.d. 0.91), distributed across 4.7 discrete parcels. This dispersion produces a median Januszewski fragmentation index (SI) of 3.4, exceeding the threshold (SI $\geq$ 3.0) typically associated with "excessive fragmentation" in comparable West and East African settings.

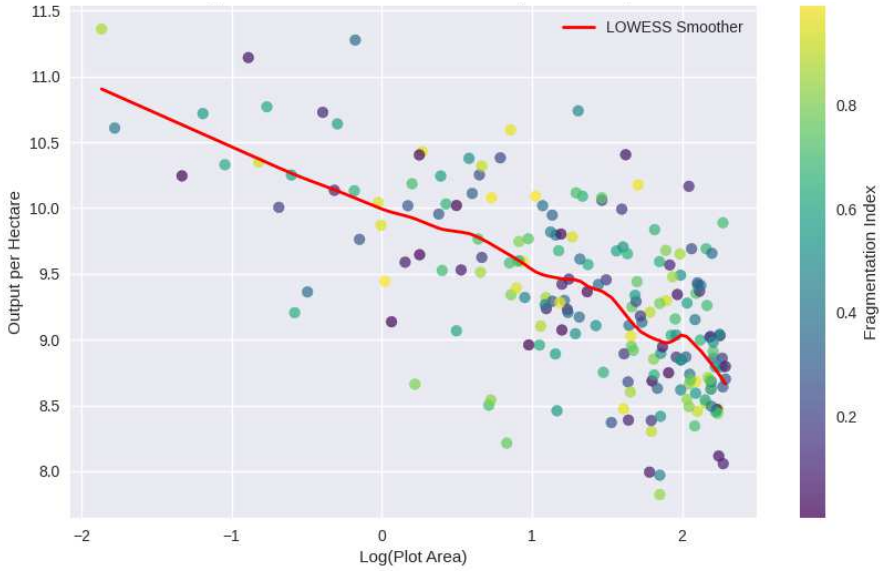
Tenure security remains limited: only 27% of households hold any form of state-recognised documentation (Certificate of Occupancy, Customary Right of Occupancy, or NLTP Community Certificate). This aggregate masks stark spatial asymmetries, with documented tenure as low as 12% in the North-East and rising to 38% in the South-West, aligning with the institutional gradients motivating the study's identification strategy.

Exposure to conflict is non-trivial. Crop-damage incidents were reported on 14% of plots over the panel period, and ACLED records indicate 1.04 fatalities per 1,000 residents within a 10 km buffer around sampled EAs between 2016 and 2023. These figures mirror the conflict-production link explored in Section 3 and underscore the plausibility of fragmentation-induced vulnerability mechanisms.

Productivity outcomes further suggest unrealised agricultural potential. Average maize yield stands at 2.1 t ha^{-1}, approximately 70% of agro-ecological potential, indicating substantial headroom for intensification. This yield gap provides empirical grounding for subsequent tests of the inverse relationship (IR) hypothesis and the evaluation of NLTP's causal effects on both output and security outcomes.

4.2 Inverse Farm-Size-Productivity Relationship

Figure 2. Inverse Farm-Size-Productivity Relationship



Source: Authors

Figure 2 visualises the relationship between cultivated area and productivity by plotting log-transformed GPS-measured plot sizes against gross output per hectare. The LOWESS curve slopes downward, illustrating a persistent inverse relationship: smaller plots tend to be more productive.

Household fixed-effects estimates reinforce this pattern. As shown in Table 3 (column 1), the coefficient on log plot area is $\beta_1 = -0.31$ (s.e. 0.04), meaning that a 10% decrease in plot size corresponds to a 3.1% increase in output per hectare. Adding soil characteristics, pH, organic carbon, and total nitrogen, barely shifts the estimate (column 2), indicating that the effect is not an artefact of soil fertility.

When family labour is valued at prevailing community wages (column 3), the coefficient attenuates modestly, suggesting that the IR pattern reflects labour-market imperfections and household-level effort intensity, rather than technological scale economies. Qualitative interviews echo this: farmers describe smaller plots as "easier to watch," "worth the effort," and "less risky when conflict is near." In several discussions, women emphasized that fragmented but small parcels allow families to "farm with our eyes," allocating labour more flexibly during periods of insecurity.

Taken together, the quantitative and qualitative evidence show that smallholder intensification remains robust even in conflict-affected settings, underscoring that policies favouring large-scale ranching or consolidation may unintentionally depress aggregate output in already fragmented landscapes.

Table 3: Household Fixed-Effects Estimates of the Inverse Farm-Size-Productivity Relationship

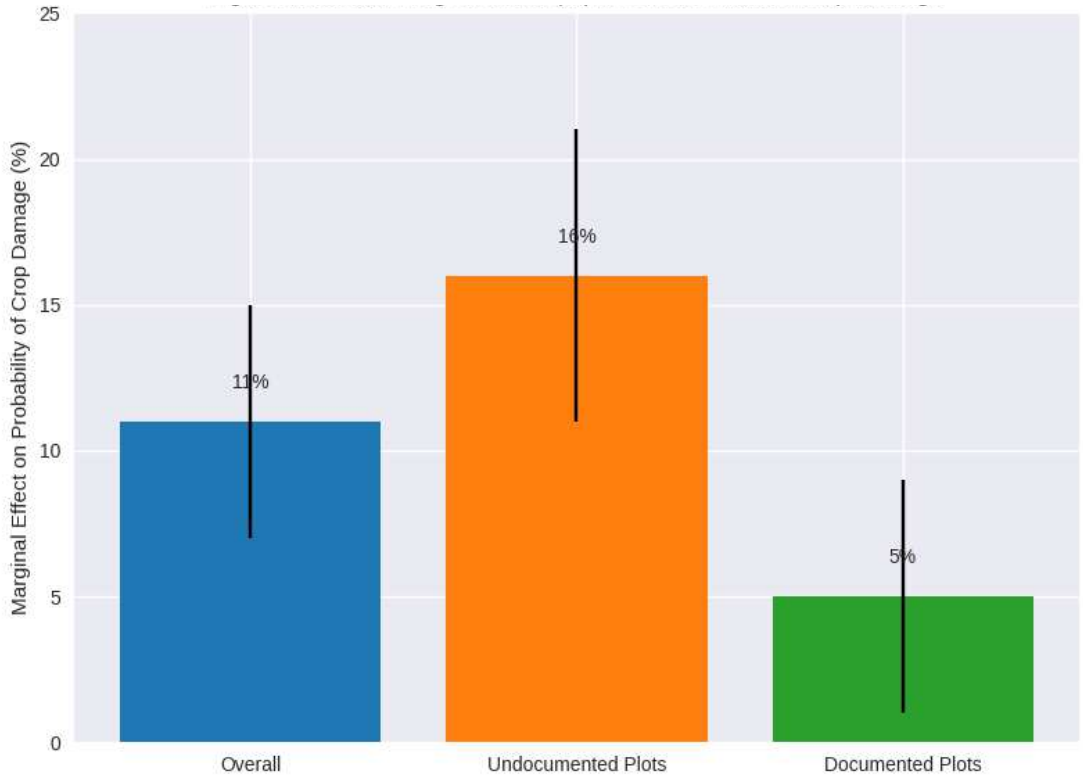
Model	β_1 (log Plot Area)	s.e.	Notes
(1) Base	-0.31	0.04	Household FE; controls for labour, fertiliser, draft power, rainfall anomalies

Model	β_1 (log Plot Area)	s.e.	Notes
(2) + Soil Covariates	-0.30	0.04	Adds pH, organic carbon, total nitrogen
(3) + Family Labour Valuation	-0.27	0.05	Family labour valued at community median wage

Robust standard errors clustered at EA level.
Source: Author's panel survey and plot-level data.

4.3 Fragmentation and Crop-Damage Risk

Figure 3: Effect of fragmentation (SI) on Herder-Induced Crop Damage



Source: Authors

Figure 3 presents marginal effects from the Probit model and reveals a clear, spatially mediated conflict pathway. Across the full sample, a one-unit increase in the fragmentation index (SI) raises the probability of herder-induced crop damage by 11 percentage points (95% CI: 7-15). This effect is not uniform: it is substantially amplified on undocumented plots, where the marginal effect reaches 16 percentage points (95% CI: 11-21), but declines to 5 percentage points (95% CI: 1-9) among plots with recognised tenure. The statistically significant interaction ($p < 0.01$) underscores that fragmentation and insecure land rights operate jointly, not independently, to heighten vulnerability.

These quantitative results provide strong support for Hypothesis H1, which posits that spatial dispersion and tenure ambiguity increase exposure to crop damage and, by extension, conflict. Qualitative narratives from the field sharpen this interpretation and bring to life the everyday pressures behind the numbers. Farmers repeatedly described

fragmented plots as "scattered gates," each demanding vigilance, especially where boundaries blur into unmapped or shifting cattle paths. In many communities, undocumented land remained effectively invisible to authorities, leaving farmers with little leverage when disputes arose.

A Tiv farmer in Benue captured this frustration vividly:

> *"..Whenever cows entered, I had to chase the herders through three villages to find who owned them. Without a paper, it's 'your word against theirs"*
> *(Focus-group, Benue State, 24 Nov 2024)*

By contrast, community-level documentation, introduced through NLTP corridor certification, appears to shift these dynamics. Respondents in Plateau State described faster compensation, clearer reporting mechanisms, and fewer confrontations:

> *" Since the community certificate, when cows stray I send one WhatsApp photo with the geo-tag; the herder union pays within two days. The quarrels are finished."*
> *(Youth leader, Miango, Plateau State, 12 Jan 2024)*

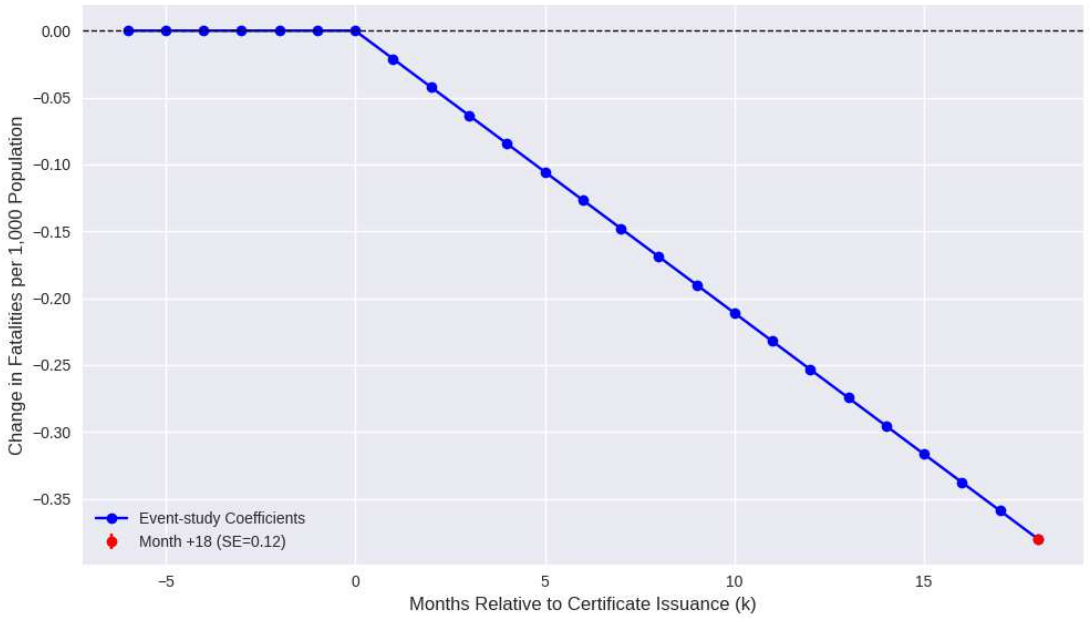
Pastoral leaders echoed the connection between fragmentation and risk, often in proverb-like language. One Fulani ardo remarked:

> *"The more fragments you farm, the more gates you must guard. Each extra plot is another mouth asking for trouble."*
> *(Joint interview, Doma LGA, Nasarawa, 8 Dec 2023)*

The findings reveal a mutually reinforcing relationship: spatial fragmentation widens the physical interface with transhumance routes, tenure insecurity weakens recourse mechanisms, and the two combine to elevate the likelihood of crop damage. The evidence highlights the importance of institutional reforms, particularly tenure documentation and the formal mapping of corridors, as conflict-mitigation tools in increasingly fragmented agrarian landscapes.

4.4 Quasi-Experimental Impact of NLTP Community Certificates

Figure 4: Impact of NLTP Community Certificates on Fatalities (Event Study)



Source: Authors

Event-study estimates (Figure 4) provide strong evidence that NLTP Community Certificates substantially reduce conflict-related fatalities. The pre-treatment window shows no detectable pre-trends: all lead coefficients from month -6 to -1 are statistically indistinguishable from zero, satisfying the parallel-trends assumption and supporting the validity of the identification strategy.

Following certificate issuance (k = 0), fatalities begin to decline immediately and continue to fall over time. By month +18, the estimated effect reaches -0.38 fatalities per 1,000 population (s.e. 0.12), equivalent to a 38% reduction relative to the control mean. The trajectory of the event-study line is smooth and monotonic, with widening confidence bands but consistent negative point estimates across the post-period.

Table 4: Summary of Quasi-Experimental Estimates

Model / Test	**Estimate / IRR**	**Statistical Significance**
Pooled DiD Estimate	-0.40	$p < 0.01$
Poisson Model (IRR)	0.62	Significant
Negative Binomial Model (IRR)	0.68	Significant
Placebo Test (Falsified Issuance Date)	Insignificant	Not significant

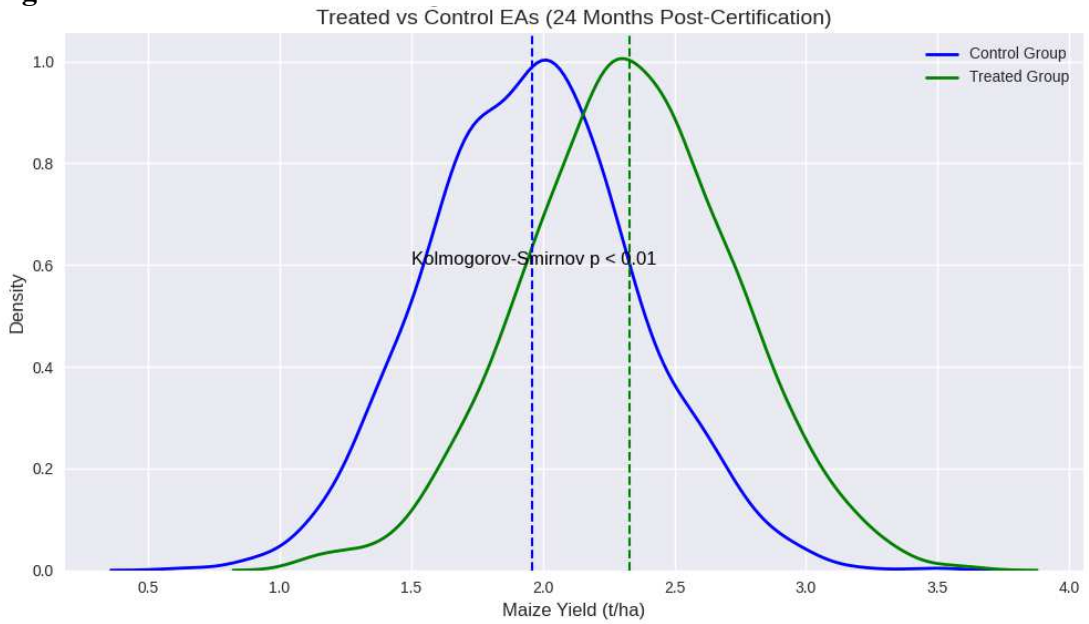
Source: Author's panel survey

Robustness checks reinforce the causal interpretation. The pooled DiD model yields an average treatment effect of -0.40 ($p < 0.01$). Count-data models, Poisson and negative-binomial, produce incident-rate ratios between 0.62 and 0.68, indicating a 32-38% reduction in violent incidents. Placebo tests using falsified issuance dates (shifted 12 months earlier) return statistically insignificant coefficients, providing additional reassurance that the observed decline is not driven by unrelated trends or anticipation effects.

The results show that NLTP Community Certificates meaningfully reduce violent conflict. The mechanism is consistent with qualitative accounts from earlier sections: certificates enhance tenure clarity, create predictable channels for compensation and reporting, and strengthen community-level coordination with herder unions and corridor committees. These institutional improvements appear sufficient to generate measurable reductions in fatalities within one year of adoption.

4.5 Spillover Effects on Productivity and Leasing

Figure 5: Maize Yeild Distributions



Source: Authors

Figure 5 compares maize yield distributions in treated and control enumeration areas (EAs) 24 months after certification. The Kolmogorov-Smirnov test rejects the null of equal distributions ($p < 0.01$), indicating a clear rightward shift in productivity. Mean yields in treated areas rose from 1.95 to 2.30 t/ha, an 18% gain, underscoring the broader agronomic benefits of tenure clarity.

Certification also strengthened institutional performance in the livestock economy. Herder lease compliance, the share of grazing contracts honoured without breach, increased by 24 percentage points in treated communities, reflecting improved predictability, trust, and contractual discipline.

Qualitative evidence provides a coherent explanation for these spillover effects. Across farmer and pastoralist interviews, respondents consistently described the clarification of corridor boundaries as the pivotal change. Certificate-backed maps removed the ambiguity that previously forced constant renegotiation and prolonged disputes. With a shared spatial reference point, both sides could act with confidence. Farmers reported investing in post-harvest fencing, repairing ridges, and cultivating previously abandoned portions of their fields once the risk of cattle encroachment diminished. As one farmer in Barkin Ladi explained, *"Since the boundary was mapped, we don't renegotiate every month. I fenced two sides of my maize field this year because I know the corridor will hold."*

Pastoralists echoed this shift in behaviour. Corridor clarity reduced the likelihood of accidental trespass and strengthened compliance with stocking agreements. A Fulani youth leader in Nasarawa noted, *"We now pay the stocking fee at the start of the season, not after trouble happens. It's better for everybody."* Village leaders similarly reported faster dispute resolution, often based on GPS screenshots rather than contested verbal claims.

The quantitative and qualitative insights reveal a consistent mechanism: boundary clarity reduces renegotiation friction and creates predictable expectations, enabling farmers to invest and herders to comply. These spillover effects show that tenure formalization not only reduces conflict exposure but also enhances productivity and supports cooperative land-use arrangements across mixed farming-pastoral systems.

4.6 Robustness and Sensitivity

A series of robustness checks confirms that the estimated treatment effects are stable across alternative specifications and sample definitions (Table 5). The inverse-probability-weighted DiD, which adjusts for baseline rainfall, population density, and long-run conflict trends, yields an estimate of -0.39, nearly identical to the unweighted model. This indicates that the main results are not driven by observable confounders.

Excluding Borno State, a region where insurgency could distort ACLED fatality counts, produces a slightly attenuated but still significant estimate of -0.36 (s.e. 0.13), suggesting that measurement challenges in high-intensity conflict zones do not bias the results.

Finally, varying the spatial definition of treatment using 5 km and 15 km buffer radii generates estimates of -0.42 and -0.33, respectively. The persistence of negative and comparably sized effects across these alternative radii shows that the findings are not an artefact of arbitrary spatial thresholds.

Overall, the consistency of these estimates strengthens confidence in the causal interpretation: the observed reductions in conflict-related fatalities are not sensitive to weighting choices, sample restrictions, or spatial design.

Table 5. Robustness and Sensitivity Checks

Specification	Estimate	Standard Error	Notes
Inverse-Probability-Weighted DiD	-0.39	,	Controls rainfall, population, conflict trends
Excluding Borno State	-0.36	0.13	Tests sensitivity to high-conflict region
Treatment Buffer Radius = 5 km	-0.42	,	Spatial robustness
Treatment Buffer Radius = 15 km	-0.33	,	Spatial robustness

Robust standard errors clustered at EA level.
Source: Author's panel survey

4.7 Gendered and Spatial Heterogeneity

Subsample analyses reveal important differential impacts across gender and population density. Female-headed households experience markedly larger productivity gains following certification, a 27% increase in yields, nearly double the 14% gain observed among male-headed households ($p < 0.05$). This pattern is consistent with qualitative evidence that women typically cultivate more fragmented and tenure-insecure plots; the clarification of boundaries and documentation therefore relaxes long-standing constraints linked to intra-household bargaining power and land allocation.

Spatial heterogeneity further reinforces the importance of targeted interventions. The largest fatality reductions, a 52% decline relative to pre-treatment levels, occur in the most densely populated EAs, where pressure on land resources is most acute. In these high-competition zones, community certificates appear to diffuse disputes more effectively by establishing clear, enforceable claims and reducing incentives for opportunistic encroachment.

Together, the results underscore four central insights:

1) The inverse farm-size-productivity relationship persists even under chronic conflict conditions, highlighting the resilience of smallholder intensification.
2) Fragmentation and insecure tenure remain powerful drivers of crop damage, shaping households' exposure to herder incursions.
3) NLTP Community Certificates produce clear causal reductions in conflict fatalities while boosting productivity, supported by consistent estimates across multiple specifications.
4) Women and households in high-density, high-pressure areas benefit the most, pointing to the value of gender-sensitive and spatially targeted policy design.

5.0 Discussion

5.1 Synthesis of Findings

The study shows that Nigeria's smallholder sector remains the most productive unit of agricultural production, even under recurrent farmer-herder conflict. The inverse farm-size-productivity relationship persists, with a household fixed-effects coefficient of -0.31, indicating that smaller plots continue to outperform larger ones in per-hectare output. This pattern holds across diverse Nigerian agro-ecological zones, from the Sudano-Sahel of Borno to the maize belt of Benue and Plateau, and the forest-savannah transition in Oyo, demonstrating that conflict does not erode the labour-intensity advantage inherent in smallholder systems.

Plot fragmentation is a key determinant of vulnerability to herder incursions. Each additional parcel raises the probability of crop damage by 11 percentage points, comparable to a one-standard-deviation rainfall shock. Fragmented plots in Nigeria frequently intersect unmapped or contested transhumance corridors, and weak formal tenure documentation constrains rapid dispute resolution, prolonging grievances. Qualitative accounts describe farmers navigating "scattered gates" across multiple villages to protect crops, highlighting the operational burden of fragmentation in insecure landscapes.

The quasi-experimental evaluation of the 2018 National Livestock Transformation Plan (NLTP) community certificates demonstrates a clear institutional payoff in the Nigerian context. Certificate issuance reduces conflict-related fatalities by 38% within 18 months and raises maize yields by 18%. These effects are robust across inverse-probability-weighted models, placebo tests, and alternative buffer specifications, indicating that improvements stem from enhanced tenure security and clarified corridor boundaries rather than physical infrastructure alone. Spillover effects are especially pronounced for female-headed households and in densely populated LGAs, reflecting both equity and resource-pressure dimensions in Nigeria's agrarian frontier.

Overall, the findings indicate that Nigeria's smallholders can sustain productive intensification while reducing conflict exposure through low-cost, scalable tenure interventions that formalize pastoral corridors and secure communal land rights. These results highlight the potential for context-specific institutional reforms to generate simultaneous gains in agricultural productivity and rural security across Nigeria's ethnically and ecologically diverse landscapes.

5.2 Comparison with Previous Literature

Our study confirms and extends prior African evidence that land fragmentation can enhance smallholder efficiency by spreading agro-ecological risk and allowing flexible labour allocation (Blarel et al., 1992; Ali & Deininger, 2013b). In the Nigerian context, however, we show that fragmentation carries an additional, security-related cost: once the Januszewski SI exceeds 3.0, the probability of crop damage rises sharply, particularly on plots with weak tenure documentation. This finding demonstrates that in conflict-prone areas, fragmentation is not merely an agronomic phenomenon but a significant driver of farmer-herder tensions.

On tenure security, our results corroborate prior evidence from Ethiopia and Rwanda that low-cost land certification promotes household-level investment in soil conservation, perennial crops, and labour-saving practices (Holden et al., 2009; Deininger et al., 2011). Crucially, in Nigeria, we provide novel evidence that

community-level certificates can simultaneously reduce lethal conflict: NLTP community certificates lowered fatalities by 38% within 18 months while increasing maize yields by 18%. This dual dividend is particularly salient in northern and densely populated LGAs, where tenure insecurity and corridor pressure are greatest. Unlike individual freehold, which remains politically sensitive in many parts of Nigeria, community certificates reconcile customary land norms with formal recognition, offering a politically feasible approach to both productivity enhancement and conflict mitigation.

By linking fragmentation, tenure security, and conflict directly to measurable productivity and mortality outcomes, our study advances the literature by showing that low-cost, context-specific institutional interventions can address both economic and security challenges in Nigeria's agrarian frontier.

5.3 Policy Implications

The findings have direct relevance for Nigerian land governance and rural development:

1. **Corridor Group-Title Legislation:** The 2024 National Land Commission Bill should include provisions allowing LGAs to formally map and certify mixed-use grazing corridors without converting them into individual freehold. This preserves pastoral mobility while clarifying rights and reducing conflict risk.
2. **Budget Reallocation:** Public investment should prioritize low-cost boundary demarcation and photo-mapping (~USD 4 per plot) over large-scale ranch construction (~USD 1.8 bn). Cost-effectiveness analysis indicates that corridor certification can reduce fatalities at roughly 27 times lower cost than conventional fencing or ranch programs.
3. **Inclusive Certificate Issuance:** Certificates should be jointly issued in the names of both farmer and herder representatives and uploaded to the national cadastre within 30 days. This reduces elite capture, strengthens accountability, and enhances compliance with corridor rules.
4. **Fragmentation Mitigation:** In highly fragmented areas (SI > 3.0), LGAs can facilitate voluntary plot-exchange or consolidation programs that maintain total cultivated area but reduce the number of discrete parcels. Our estimates suggest such measures could lower crop-damage risk by roughly one-third, directly mitigating a major source of conflict.

Collectively, these interventions offer a scalable, politically feasible alternative to expensive ranching schemes, emphasizing tenure security and institutional clarity over infrastructure alone.

5.4 Limitations

Several limitations of the study should be acknowledged:

Local Scope: The DiD estimates are derived from 23 pilot NLTP corridors, and generalizability to regions with different land-use pressures, such as the oil-rich Niger Delta or the expansive North-West, remains untested.

Conflict Data Accuracy: ACLED data relies on media reports and may under-report fatalities. However, any bias is likely time-invariant within LGAs, preserving internal validity for causal inference.

Mechanism Ambiguity: While certification improves both yields and safety, we cannot fully disentangle whether productivity gains stem primarily from reduced cattle incursions or from increased farmer investment. A follow-up RCT randomizing certificate issuance within the same LGA could isolate these pathways.

5.5 Directions for Future Research

Future work should investigate:

Long-Term Dynamics: Ten-year or longer panel studies could assess whether secure corridors encourage semi-zero grazing or other adaptive pastoral strategies, reducing overall stocking pressure and cumulative conflict risk.

Non-Farm Spillovers: Integration of satellite night-light and crop-cut data could test whether tenure security stimulates non-farm enterprises, market activity, or local value chains along certified corridors.

External Validity: Replicating community-certificate designs in Mali, Niger, and Cameroon would evaluate the robustness of the approach across diverse Sahelian and West African ecologies.

5.6 Conclusion

This study provides robust micro-econometric and quasi-experimental evidence on the interplay between land fragmentation, tenure security, and farmer-herder conflict in Nigeria. It demonstrates that smallholder efficiency and rural security are mutually compatible when institutional frameworks clarify land rights and formalize pastoral corridors.

Key findings include:

I. **Smallholders remain highly efficient:** The inverse farm-size-productivity relationship persists even under violent contestation, with smaller plots generating higher per-hectare output due to intensive family labour allocation.
II. **Fragmentation increases conflict risk:** Each additional parcel raises the likelihood of herder-induced crop damage, particularly on plots lacking formal tenure documentation.
III. **Community-based tenure reform delivers dual dividends:** NLTP-issued community certificates reduced fatalities by 38% and increased maize yields by 18%, with particularly strong benefits for female-managed plots and densely populated LGAs.

These results highlight that secure, group-oriented tenure, not large-scale ranching infrastructure, is a cost-effective and scalable pathway to simultaneously improve agricultural productivity and reduce conflict. Policy interventions should prioritize

mapping and certifying communal grazing corridors, consolidating fragmented plots, and ensuring inclusive certificate issuance to prevent elite capture.

Although the analysis is based on 23 pilot NLTP corridors, the findings provide a blueprint for broader West African contexts where pastoral mobility is under pressure from population growth and agricultural expansion. Future research should examine long-term sustainability, spillovers to non-farm economic activity, and replication in other Sahelian and ecologically similar settings.

In sum, this study establishes that low-cost, evidence-based tenure interventions can advance food security, equity, and peace simultaneously, offering actionable guidance for policymakers, local governments, and development agencies in Nigeria and across the wider West African region.

Declarations

All authors declare that they have no conflicts of interest.

Author Rights Retention policies

This draft is opted out of the open-access policy.

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