

Necessary but not Sufficient: Rural Road Rehabilitation, Agricultural Productivity and Climate Risk in Zambia's Breadbasket Districts

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ABSTRACT

Rural roads are frequently promoted as a tool for increasing smallholder agricultural productivity, yet evidence from real-world, climate-stressed contexts remains mixed. This paper examines how rural road rehabilitation under the Zambia Improved Rural Connectivity Project has affected agricultural productivity and resilience among small-scale farmers in Nyimba and Chibombo districts. Using a concurrent mixed-methods design, the study combines survey data from 372 households, stratified by district and distance from rehabilitated roads, with qualitative interviews, focus group discussions, and key informant interviews. The analysis focuses on land ownership and activation, cropping patterns and yields for maize, sunflower, soya beans and groundnuts over two recent agricultural seasons, including the climatically adverse 2023/24 season. Results show that land ownership is widespread in both districts and that improved roads have supported land activation and crop diversification, particularly in previously more peripheral parts of Nyimba. Maize cultivation remains entrenched, but participation in commercial oilseed and legume crops has expanded or been sustained along rehabilitated corridors. However, yield outcomes are highly volatile: maize and soya yields contracted sharply in 2023/24 season, particularly in Chibombo, despite improved physical access to depots and markets, and sunflower and groundnut yields are uneven across distance bands and local agro-ecologies. Interpreted through the Spatial Development Theory and the Sustainable Livelihoods Framework, the findings support a “necessary but not sufficient” interpretation: Improved Rural Connectivity Project roads raise the ceiling of feasible productivity and help farmers stay engaged in key value chains, but realised productivity gains depend critically on climate, agronomy, liquidity and local market and service ecosystems. Policy implications emphasise integrating rural road investments with climate-smart agriculture, timely input systems and rural finance.

Keywords: Rural roads; Agricultural productivity; Climate risk; Small-scale farmers; Zambia.

INTRODUCTION

Rural Roads, Markets and Productivity Globally

Rural transport infrastructure is widely recognised as a critical enabler of agricultural intensification, market integration, and poverty reduction in low- and middle-income countries, serving as a foundational public good central to contemporary efforts to raise productivity and foster inclusive rural growth, particularly in Sub-Saharan Africa. In agrarian economies, feeder roads provide the essential conduits through which inputs, outputs and services move between dispersed farming communities and market centres. A substantial body of empirical work, from broader global studies to recent African contexts, links improved rural roads to reduced transport costs, higher input use, expansion of cultivated area and increases in farm incomes and output (Bucheli et al., 2018; Takada et al., 2021; Chen et al., 2023; Gebresilasse, 2023). However, the magnitude of these effects varies substantially; where networks are weak, small-scale farmers face high costs, delayed input delivery, and increased post-harvest losses, which depress yields and discourage investment. Consequently, the central policy

concern is not simply whether roads matter, they clearly do, but the extent to which they deliver sustained gains under real-world constraints. A growing body of research cautions that investments do not automatically translate into sustained productivity when climate risk, weak input systems, thin markets and binding liquidity constraints remain unaddressed (Njenga & Opiyo, 2021; World Bank, 2024; Liu & Wen, 2025).

Productivity Challenge, Vulnerability and the Role of Rural Roads in Zambia

Zambia provides a compelling context for interrogating the nexus between rural infrastructure and agricultural productivity. The country remains predominantly rural, with a large share of households relying on small-scale agriculture for their livelihoods. However, productivity growth in the sector has been modest relative to population growth and urban food demand (Tembo et al., 2019; World Bank, 2024). Despite considerable agroecological potential in "breadbasket" regions such as the Eastern and Central Provinces, many small-scale farmers cultivate small plots with low and variable yields, constrained by limited access to quality inputs, extension services and reliable markets (Burke et al., 2020). Rural poverty and food insecurity, exacerbated by recurrent droughts and erratic rainfall, are amplified by poor rural road infrastructure, which raises transaction costs and restricts market access. Consequently, the government and development partners have positioned investments in rural roads as a key instrument for unlocking the agricultural potential of Zambia (World Bank, 2020; 8NDP, 2022).

Within this national context, the Improved Rural Connectivity Project has rehabilitated key primary feeder roads with the explicit objective of reducing travel times and lowering transport costs to facilitate agricultural trade. The contrasting districts of Nyimba and Chibombo (target areas for the Improved Rural Connectivity Project) offer a natural comparative test bed. Nyimba District in Eastern Province has historically been characterised by relatively weak connectivity, with many feeder roads becoming impassable during the rainy season. In contrast, Chibombo District in Central Province occupies a more strategic position along major transport corridors, hosting a mix of small-scale and emerging medium-scale farmers with better access to processors and aggregators.

While emerging evidence confirms that Improved Rural Connectivity Project roads have improved market accessibility, there is relatively little empirical evidence on how far such investments translate into concrete, sustained shifts in smallholder productivity, especially in the face of climatic and economic shocks. Much of the existing literature measures impact using metrics such as distance to market or marketed surplus, without systematically examining crop-specific land activation, yields, and diversification under real-world shocks (Tamene & Megento, 2017; Bucheli et al., 2018; Burke et al., 2020).

The paper has two main objectives. First, it assesses how the Improved Rural Connectivity Project road rehabilitation has affected land activation, cropping patterns, and yields for four key crops (maize, sunflower, soya beans and groundnuts) among small-scale farmers in Nyimba and Chibombo, comparing households located within 2 km and 2–5 km of rehabilitated roads. Second, it explores how climate, agronomy and liquidity constraints have interacted with improved connectivity to shape productivity outcomes and diversification trajectories.

The analysis is guided by the following questions: (i) To what extent has the Improved Rural Connectivity Project road rehabilitation supported land activation and sustained or expanded participation in key staple and commercial crops? (ii) How have yields for the four focus crops evolved across districts and distance bands, particularly in the adverse 2023/24 season? and (iii) How do farmers and local actors explain the observed productivity dynamics, and what does this reveal about the conditions under which roads can support resilient agricultural growth?

Conceptual Framework

This paper adopts a broad, multi-dimensional understanding of agricultural productivity, extending beyond simple yield per hectare to encompass the intensity and stability of land use, crop diversification, reductions in post-harvest losses and the capacity of farmers to sustain production in the face of shocks. Rural roads are theorised to influence these dimensions through several interrelated mechanisms. Improved physical access should lower the cost and increase the timeliness of obtaining critical inputs like fertiliser and seed, facilitate

access to mechanisation services and enable faster movement of produce to markets, thereby reducing spoilage and the need for distress sales (Ellis, 2000). Enhanced connectivity may also encourage a shift towards more commercial, higher-value crops, such as oilseeds and legumes, where reliable market channels exist. To analyse these dynamics, the paper integrates two complementary conceptual lenses: Spatial Development Theory and the Sustainable Livelihoods Framework.

The Spatial Development Theory provides a macro-level perspective on how transport investments reshape economic geography by reducing peripherality and creating new growth corridors (Krugman, 1991; Ako & Wannie, 2022). Applied to the contexts of Nyimba and Chibombo, this suggests that the Improved Rural Connectivity Project road rehabilitation may differentially integrate farmers into regional markets, potentially creating new spatial gradients of opportunity between roadside and off-corridor areas.

However, productivity gains are not automatic and are increasingly viewed through a resilience lens. Recognising that road improvements occur within a wider "vulnerability context," the paper employs the Sustainable Livelihood Framework as its core analytical framework (Scoones, 1998). This framework centres on rural households' asset portfolios (their natural, financial, human and social capital) and how these interact with external shocks, trends, and institutional processes. Updated by contemporary scholarship on climate risk (Kundu et al., 2020), the Sustainable Livelihoods Framework explicitly positions physical capital, such as roads, as one asset among many. It highlights how climatic variability, price volatility, and limited access to credit or insurance can constrain the extent to which farmers can capitalise on the new opportunities created by better infrastructure.

Thus, the integrated conceptual approach posits that the impact of rural roads on productivity is mediated by a household's broader livelihood context. Improved connectivity (a form of physical capital) is expected to enhance productivity by facilitating market integration (per Spatial Development Theory), but its ultimate effect on resilient production outcomes is contingent upon access to other forms of capital and its exposure to climatic and economic shocks of a household (per Sustainable Livelihood Framework). This framework guides the empirical investigation into how roads shape land activation, cropping patterns, and yields under variable seasonal conditions.

Knowledge Gaps

Despite a substantial empirical literature linking rural roads to agricultural productivity, critical knowledge gaps persist, particularly within African small-scale farming systems. While global studies demonstrate that road upgrades can increase yields and expand cultivated areas, these effects are highly heterogeneous and contingent on complementary policies and institutions. In the African context, similar research finds that improved roads are associated with greater input use and higher marketed surplus (Imi, 2020; Ewnetu, 2023). However, there is a scarcity of granular, mixed-methods evidence from Zambia that traces the evolution of cropping patterns and yields in the immediate years following road rehabilitation, especially across seasons of variable climatic quality. Existing work often focuses on broader provincial trends or market participation metrics rather than on the crop-specific productivity responses within specific road corridors (Tembo et al., 2019; Burke et al., 2020).

Significantly, few studies explicitly examine how the productivity effects of road improvements interact with "bad years", seasons characterised by drought, pests, or input delays, or how these effects differ between districts with contrasting baseline market access (like Nyimba and Chibombo) and between households at varying distances from rehabilitated roads. These gaps limit our understanding of whether road investments alone are sufficient to deliver sustained, resilient productivity gains under real-world risk conditions, a central concern framed by the Sustainable Livelihoods Framework.

Aim, Research Questions and Theoretical Framing

Against this backdrop, this paper aims to evaluate how feeder road rehabilitation under the Improved Rural Connectivity Project has influenced agricultural productivity and resilience among small-scale farmers in Nyimba and Chibombo districts. The analysis focuses on changes in land use, cropping patterns, and yields for key staple and commercial crops (maize, sunflower, soya beans and groundnuts) across two recent seasons with markedly different rainfall outcomes.

The main research question is: How have rehabilitated rural roads affected agricultural productivity among small-scale farmers in Nyimba and Chibombo districts, and how robust are these effects under adverse seasonal conditions?

Three specific questions guide the empirical work: (i) How do land use and cropping patterns differ by district and by distance from the rehabilitated roads? (ii) How have yields per hectare for major crops changed between the 2022/23 and drought-affected 2023/24 seasons? and (iii) How do farmers interpret these changes in terms of opportunity, risk, and medium-term livelihood strategy?

The analysis is framed by an integrated conceptual approach. The Spatial Development Theory (Friedmann, 1966) informs how roads reshape core-periphery relations and spatial opportunity. Complementing this, the Sustainable Livelihoods Framework (Scoones, 1998; Ellis, 2000) provides the core lens for analysing how roads (physical capital) interact with other household capital assets within a vulnerability context of climate and market shocks to shape productivity and resilience outcomes.

Contribution and Structure of the Paper

By addressing these questions, the paper makes three key contributions. Empirically, it provides novel, district-comparative and crop-specific evidence on small-scale productivity responses to road rehabilitation in Zambia, using mixed-methods data from two contrasting districts across a climate-stressed season. Conceptually, it advances the argument that while roads expand the feasible ceiling of productivity by improving market access (as per Spatial Development Theory), realised gains are mediated by risk and asset constraints (as per the Sustainable Livelihoods Framework), underscoring that roads are "necessary but not sufficient". Policy-wise, the findings directly inform the design of integrated interventions that combine road investment with targeted support for climate resilience, inputs and finance.

The remainder of the paper is structured as follows: Section 2 reviews the literature on Zambia's productivity challenge and the conceptual links between roads, productivity, and resilience; Section 3 outlines the methodology; Sections 4 and 5 present and discuss the empirical findings; and Section 6 concludes with implications for policy and future research.

LITERATURE REVIEW

Rural Roads, Market Access and Agricultural Productivity

Recent empirical work continues to affirm that rural road investments are closely associated with improvements in agricultural performance, though their effects are heterogeneous and context-dependent. A global body of evidence underscores the dual role of connectivity: it directly lowers transaction costs and indirectly stimulates commercialisation and structural transformation. Studies from Ethiopia, China and Kenya demonstrate that road expansions raise farm productivity, contribute to sectoral growth, and enhance long-term marketed output (Gebresilashe, 2023; Liu & Wen, 2025). Spatially explicit analyses further confirm local intensification, linking road quality upgrades to higher agricultural output and increased input use in surrounding areas.

However, a consistent finding across diverse contexts, from Indonesia and Nigeria to sub-Saharan Africa, is that the magnitude and distribution of these benefits are mediated by the broader local ecosystem. Research indicates that the largest productivity gains accrue where roads are combined with complementary services and supportive institutions, such as agricultural extension, access to finance, and developed market structures (Kamaludin & Qibthiyah, 2022). In the Zambian context, studies highlight that improved market access can enhance smallholder commercialisation, yet benefits are often spatially uneven and concentrated in better-connected districts (Tembo et al., 2019; Burke et al., 2020). This reinforces the view that infrastructure alone is insufficient; its effectiveness is contingent on interactions with local market structures, service ecosystems, and household-level constraints (Tamene & Megento, 2017; Bucheli et al., 2018).

These insights provide a critical foundation for assessing the influence of the Improved Rural Connectivity Project in Nyimba and Chibombo. They affirm roads as a vital enabling factor while simultaneously necessitating a granular, district-comparative analysis that examines crop-specific productivity outcomes under real climatic

and economic stress, moving beyond broader metrics of market participation to understand the nuanced pathways to resilient growth.

Evidence from Sub-Saharan Africa and Zambia

Emerging research within Sub-Saharan Africa provides critical context-specific insights into how rural roads shape agricultural livelihoods, particularly through pathways of commercialisation and under conditions of climate risk. Recent evidence from Ethiopia, Nigeria and Tanzania confirms that improved connectivity is associated with higher technical efficiency, increased market participation, and greater household resilience to shocks, often by facilitating diversification into off-farm opportunities (Ewnetu, 2023; Isah, 2024; Dumas & Játiva, 2024). A central finding, however, is that the commercialisation and income benefits are seldom uniform, as they are frequently mediated by farmers' initial asset status and, critically, their distance from the improved road corridor.

This nuanced understanding is reflected in the Zambian context. While improvements in physical infrastructure are evident, studies consistently identify persistent binding constraints that mediate their impact. Research highlights that distance and transport costs continue to significantly shape smallholder access to staple crop and input markets (Tembo, 2019). More fundamentally, liquidity constraints at planting time remain a powerful determinant of production and marketing decisions, suggesting that road-led gains can be severely limited without complementary access to credit and finance. Furthermore, the structure and governance of national value chains, such as the maize value chain, play a decisive role in determining which actors capture the benefits of improved connectivity.

This body of work is increasingly framed within the escalating challenge of climate change, which intensifies the vulnerability context in which roads operate. Climate variability heightens production risk, while improved market integration can simultaneously expose farmers to greater price volatility (Kwame et al., 2019; World Bank, 2025). Consequently, scholars argue for a "*risk-attuned*" analytical approach that explicitly examines how infrastructure interacts with climatic and economic shocks, rather than assuming stable conditions (Natarajan et al., 2024). This perspective is directly pertinent to the study districts of Nyimba and Chibombo, where a severe drought in the 2023/24 season starkly illustrated that improved road access does not automatically insulate farmers from climate-induced yield contractions. Thus, the literature underscores that roads are a crucial enabling factor for commercialisation, but their contribution to resilient productivity depends on a complex interplay among financial access, market structures, and climate risk.

Mechanisms Linking Roads, Markets, Crop Choice and Intensification in Zambia

Recent empirical and conceptual studies have sharpened understanding of the specific mechanisms through which rural roads influence agricultural productivity and land use, with clear implications for Zambia's evolving value chains. A key mechanism is the reduction of transaction costs, which directly enhances factor mobility and market access, enabling timely procurement of inputs and sale of outputs (Liu & Wen, 2025). This connectivity can catalyse shifts in land use and crop portfolios, encouraging farmers to expand cultivated area and diversify into higher-value, market-oriented crops where reliable buyers exist (Udeuhele & Eze, 2022; Kamaludin & Qibthiyah, 2022).

Critically, research underscores that these mechanisms are significantly amplified by complementary services and institutional structures. Studies highlight strong synergies between roads and agricultural extension, where improved access lowers the cost of service delivery and increases the adoption of productivity-enhancing technologies (Gebresilasie, 2023). The broader economic environment is equally decisive; roads are most effective in stimulating commercialisation, capital intensification, and pro-poor growth when embedded within supportive market structures and social capital networks.

The Zambian literature vividly illustrates these contingent mechanisms through the lens of specific value chains. Evidence shows that medium-scale farms and agro-processors in well-connected districts can generate positive spillovers for smallholders by improving local market access and service availability (Burke et al., 2020). This is particularly relevant for the growing oilseed and legume sectors (sunflower, soya and groundnuts), where reliable, climate-resilient roads are essential for linking farmers to processors and facilitating commercial

expansion. However, the trajectory of staple crop commercialisation, such as maize, remains heavily shaped by a complex mix of infrastructure, policy and market actors (Sitko & Jayne, 2014; Tembo, 2019).

Applied to the study context, Nyimba and Chibombo demonstrate these dynamics in practice. The Improved Rural Connectivity Project roads have sustained maize participation and facilitated entry into oilseed value chains. Yet, the findings crucially reveal that realised yield outcomes are not a function of connectivity alone; they are the joint product of climate, input systems and liquidity. This underscores the central outputs emerging from the literature: while roads provide a critical foundation for market integration and can activate land and diversification, translating these opportunities into sustained productivity gains is fundamentally contingent on a favourable institutional and economic environment, especially under adverse climatic and financial conditions.

Rural Roads, Climate Risk and Resilience

A growing set of studies explicitly considers how rural roads interact with climate risk and resilience. Nakamura et al. (2020) show that in Ethiopia, households with better access to all-weather rural roads are less likely to fall into poverty following negative shocks, suggesting that connectivity enhances resilience by facilitating adjustment, diversification and access to support. Olagunju (2020) similarly documents that roads raise rural household incomes partly by enabling more flexible responses to price and climate shocks, although the strength of these effects varies across regions and livelihood strategies. In Tanzania, Ewnetu et al. (2023) argue that road improvements support agricultural commercialisation and poverty reduction, but that these gains are fragile in the face of climatic variability and may be reversed when harvests fail.

At a broader level, transport infrastructure generally improves rural livelihoods across the globe, but its impact on resilience is highly context-dependent and mediated by the availability of other forms of capital, such as savings, insurance and social networks. This resonates with the situation in Zambia's Nyimba and Chibombo districts, where the 2023/24 season was widely described as a bad year, with irregular rainfall and pest damage resulting in reduced yields of key crops despite improved physical access to depots and markets. In such contexts, road rehabilitation may increase the potential for higher productivity and commercialisation, but realised outcomes hinge on climatic conditions and farmers' capacity to manage risk. Recent work thus suggests that rural roads should be seen as part of a broader resilience strategy, whose effectiveness depends on their interaction with climate-smart technologies, risk management instruments and social protection measures, rather than as a stand-alone solution.

Perspectives on Livelihoods, Infrastructure and Spatial Development

Recent scholarship on livelihoods and rural development has revisited conceptual frameworks for understanding how infrastructure shapes opportunities and constraints. Natarajan et al. (2024) propose an updated Sustainable Livelihoods Framework that is more attuned to contemporary challenges, including climate change, market volatility and new forms of inequality. Their reformulation retains the classic focus on the asset portfolios of people (natural, physical, human, financial and social capital) but places greater emphasis on power relations and systemic risks. Kumar et al. (2023) similarly argue that sustainable livelihoods approaches remain a useful foundation for rural development policy but highlight the need to foreground infrastructure as a key component of physical capital and to link it explicitly with social and institutional dimensions. Reviewing evidence from South African municipalities, Pillay (2023) emphasises that rural road networks are central to sustaining livelihoods, yet warns that uneven investment patterns can entrench spatial inequalities.

Specifically, transport infrastructure shows that roads and other transport investments affect rural livelihoods through multiple channels: enhancing access to markets and services, shaping migration and labour decisions, and influencing social capital formation. These insights complement the more meso- and macro-level focus of studies on village roads and rural transformation (Kamaludin & Qibthiyah, 2022) and on commercialisation and poverty reduction through road improvements. Taken together, this recent literature suggests that the productivity impacts of rural road rehabilitation in Nyimba and Chibombo should be interpreted not only in terms of crop yields, but also through their effects on land activation, diversification strategies and the broader livelihood systems within which farmers operate. It also implies that spatial patterns of benefit (by district, by distance from the road and by socio-economic status) are likely to be uneven, reflecting both the geography of markets and processing facilities and the differentiated asset bases of small-scale farmers.

Spatial Development Theory, Sustainable Livelihoods and Productivity

The theoretical framing of this paper draws on Spatial Development Theory and the Sustainable Livelihood Framework as they are mobilised in recent work on infrastructure, livelihoods and risk. Ako & Wannie (2022) emphasise how transport networks and urban systems shape spatial patterns of development, with roads both reducing remoteness and creating new internal peripheries. In this view, Improved Rural Connectivity Project roads can be seen as potential growth corridors that bring Nyimba and Chibombo closer to regional markets, but also generate differences between roadside and off-corridor communities.

The Sustainable Livelihood Framework, as reinterpreted by Natarajan et al. (2024) and Kumar et al. (2023), highlights that productivity outcomes emerge from interactions between physical, natural, financial, human and social capital within a vulnerability context. Roads strengthen physical capital and, in principle, support better use of natural capital (land and rainfall) and improved financial and human capital through access to inputs, credit and extension. Yet where climate shocks, liquidity constraints and weak institutions persist, roads may raise potential more than realised productivity. It is this tension, between enhanced opportunity and constrained outcomes, that the empirical analysis of Nyimba and Chibombo seeks to unpack.

METHODOLOGY

Research Design

The study adopts a concurrent mixed-methods, comparative case study design, with a pragmatic orientation that integrates quantitative and qualitative data to examine Improved Rural Connectivity Project impacts. Quantitatively, it draws on a structured household survey of 372 small-scale farming households; qualitatively, it uses semi-structured interviews, focus group discussions and key informant interviews to explain observed patterns and capture interpretations of farmers. The comparative design across Nyimba and Chibombo is central to the analysis, given their contrasting spatial positions and market contexts.

Study Areas

Nyimba District (Eastern Province) and Chibombo District (Central Province) were purposively selected as high potential “breadbasket” districts included in the Improved Rural Connectivity Project (World Bank, 2020). Nyimba is more peripheral, with moderate rainfall, a strong maize–groundnut base and historically weaker integration into national markets. Chibombo, by contrast, is closer to Lusaka and major corridors, with more diversified crop portfolios and stronger linkages to processors and urban markets (Burke et al., 2020). In both districts, the Improved Rural Connectivity Project rehabilitated primary feeder roads intended to reduce travel time and improve all-weather access between rural communities and markets.

Sampling and Data Collection

The household survey covered 372 small-scale farming households, equally divided between Nyimba and Chibombo. A multi-stage stratified sampling procedure was used, where districts were purposively selected; enumeration areas within the Improved Rural Connectivity Project corridors were sampled to cover the study area; and households within EAs were selected using systematic random sampling. To capture spatial gradients, households were stratified by distance to rehabilitated roads: within 2 km (“directly served”) and 2–5 km (“indirectly served”).

The questionnaire included modules on demographics, land holding, crop area and yields for major crops, input use, marketing and perceptions of road and market access. For this paper, key variables are: (i) land ownership and land area cultivated; (ii) participation and area under maize, sunflower, soya beans and groundnuts; (iii) self-reported yields for these crops in 2022/23 and 2023/24; (iv) input use and timing; and (v) marketing channels.

Qualitative data come from semi-structured interviews with a purposive sub-sample of farmers in both districts (selected to reflect variation in gender, asset levels, crop portfolios and distance to road), FGDs disaggregated by gender, and KIIs with extension officers, cooperative leaders, district officials and private buyers. These instruments probed perceptions of how road rehabilitation had affected crop choices, input use, yields and resilience in different seasons.

Data Analysis

Quantitative analysis used descriptive statistics and cross-tabulations to examine land ownership, land activation, crop participation and yield changes across districts and distance bands. Where possible, simple difference-indifferences comparisons were used to compare changes between 2022/23 and 2023/24 by distance band, recognising the limitations imposed by climatic shocks.

Qualitative data were analysed using thematic analysis, with codes developed around land activation, cropspecific experiences, climate shocks, input and credit constraints and interpretations of road impacts. NVivo was used to organise transcripts and identify cross-cutting themes. Quantitative and qualitative findings were integrated at the interpretation stage, allowing farmer narratives to help explain why similar road investments produced different productivity outcomes across crops, locations and seasons.

Limitations and Directions for Further Research

This study has several limitations. First, it relies in part on farmers’ recall of past seasons and yields, which may be affected by memory and attribution biases, even though efforts were made to anchor questions to specific years and events. Second, the analysis covers only two seasons, one relatively normal and one clearly adverse, so the longer-term dynamics of productivity and resilience under improved connectivity remain unknown. Third, the focus on Nyimba and Chibombo limits the generalisability of findings to other regions of Zambia, although their contrasting spatial positions make them informative comparative cases.

Future research could extend this work by following Improved Rural Connectivity Project and non- Improved Rural Connectivity Project areas over a longer time horizon, using panel data to disentangle infrastructure effects from seasonal variability more robustly; by incorporating more detailed plot-level data on management practices, soil conditions and input use; and by comparing a wider set of districts and value chains, including horticulture and livestock. There is also scope to integrate farmer-centred qualitative research on risk perceptions and decision-making with remote sensing and spatial modelling of crop performance across different infrastructure and climate scenarios. Such work would help refine an integrated policy agenda in which roads, inputs, finance and resilience are treated not as separate silos, but as interconnected levers for achieving inclusive, climateresilient agricultural transformation in Zambia and beyond.

FINDINGS AND DISCUSSION

Land Ownership, Land Activation and Cropping Portfolios

Survey data confirm that land ownership is widespread in both Nyimba and Chibombo, providing a strong base of natural capital in line with the Sustainable Livelihoods Framework. However, the productive use of this land, or its activation and cropping intensity, varies significantly by district and proximity to rehabilitated roads, underscoring the contingent mechanisms identified in the literature review (Udeuhele & Eze, 2022; Kamaludin & Qibthiyah, 2022).

As shown in **Table 1**, proximity to the rehabilitated Improved Rural Connectivity Project corridor did not fundamentally alter land ownership. The key impact was instead on land activation. Farmers within 2 km of the roads in both districts reported a greater ability to bring idle land into cultivation. As one Nyimba farmer stated: *“Before, we had land but could not use it because bringing fertiliser or bags of seed from the BOMA was too expensive. Now, transporters come straight to our village.”* This aligns with Spatial Development Theory, illustrating how improved connectivity reduces economic peripherality, lowering the cost of exploiting latent assets and effectively expanding the production feasibility frontier.

Table 1: Percentage Distribution of Households Owning Agricultural Land by District and Distance.

District	Not more than 2 km			Between 2 & 5 km		
	Sample	Frequency	Percent	Sample	Frequency	Percent
Chibombo	78	60	76.9	108	83	76.9

Nyimba	164	138	84.1	22	19	86.4
Total	242	198	81.8	130	102	78.5

Furthermore, road rehabilitation supported crop diversification, particularly where it intersected with developed market linkages. While maize dominates in both districts, cropping portfolios differ across local value chain contexts (Burke et al., 2020). In Chibombo, stronger connections to processors facilitated greater participation in commercial oilseeds such as sunflower and soya. In Nyimba, maize-groundnut systems prevailed, with more modest engagement in other cash crops. This pattern confirms that roads enable diversification most effectively where complementary market infrastructure and buyers are present.

Crucially, these findings validate the conceptual argument that physical infrastructure is a necessary but insufficient condition for intensification. The researcher cautions that land ownership only becomes a productive advantage when complemented by accessible infrastructure and affordable transport services. The data reveal that households lacking the complementary financial capital for inputs, labour or transport continued to face barriers to intensification, even with improved roads. Thus, the Improved Rural Connectivity Project altered the potential for land use, but realising this potential depended on the broader asset portfolio of a household within the Sustainable Livelihood Framework, demonstrating that roads reshape opportunity while existing inequalities in other forms of capital mediate who can seize it.

Maize: Entrenched Participation and Volatile Yields

Maize remains the cornerstone of smallholder production in both districts, with near-universal participation across distance bands. Farmers in Nyimba and Chibombo consistently reported that “we cannot stop growing maize” because of its role in food security and eligibility for input support programmes (Tembo, 2019). The Improved Rural Connectivity Project road networks have improved access to the Food Reserve Agency depots and private buyers, reduced spoilage and transport costs per unit, and enabled more frequent marketing trips, especially for households within 2 km of rehabilitated roads.

Table 2 shows that in the relatively favourable 2022/23 farming season, maize participation was very high. In Chibombo, maize was cultivated by roughly two-thirds of households within 2 km of the rehabilitated road (67.9%) and more than four-fifths (83.3%) in the 2–5 km band. In Nyimba, engagement was even stronger, with 86% of households within 2 km and 100% within 2–5 km growing maize in 2022/23 farming season. By 2023/24, participation had declined only modestly, to about 54% and 65% in Chibombo and to 76% and 86% in Nyimba across the two distance bands. In other words, maize cultivation remained entrenched at elevated levels in both districts, even in the face of a difficult season.

Table 2: Maize Cultivation Patterns by District, Distance to Road, and Season

District	Distance to Road	Sample (N)	Season	Cultivation Rate (%)	Average Area (ha)	Average Yield (ton/ha)	Ton (yield)	df	p-value
Chibombo	≤ 2 km	78	2022/23	67.9	0.53	1.05			
	≤ 2 km	78	2023/24	53.8	0.53	0.13	1186.23	41	< 0.001
	2–5 km	108	2022/23	83.3	0.60	1.62			
	2–5 km	108	2023/24	64.8	0.62	0.30	2356.29	69	< 0.001
Nyimba	≤ 2 km	164	2022/23	86.0	0.58	1.41			
	≤ 2 km	164	2023/24	76.2	0.58	0.49	2069.08	124	< 0.001
	2–5 km	22	2022/23	100.0	0.50	0.82			
	2–5 km	22	2023/24	86.4	0.49	0.69	108.09	18	< 0.001

The more striking changes occurred in yields rather than participation or area. Average maize yields in Chibombo fell dramatically between 2022/23 and 2023/24 farming seasons: from 1.05 and 1.62 t/ha in the ≤ 2 km and 2–5 km bands, respectively, to just 0.13 and 0.30 t/ha in 2023/24. Nyimba also registered yield declines, but they were less severe: from 1.41 to 0.82 t/ha to 0.49 to 0.69 t/ha across the two distance bands. Furthermore, paired samples t-tests show that the decline in maize yields between 2022/23 and 2023/24 is statistically significant in all four district–distance groups. For Chibombo, the ≤ 2 km category shows that $t(41)=1186.23$, $p<0.001$; those under the Chibombo 2–5 km group had $t(69)=2356.29$, $p<0.001$. For the ≤ 2 km group in Nyimba, $t(124)=2069.08$, $p<0.001$; Nyimba 2–5 km: $t(18)=108.09$, $p<0.001$. The extremely large $|t|$ values indicate that the observed yield differences are many standard errors away from zero, so the probability that they are due to chance is effectively nil. In other words, the 2023/24 season produced a statistically robust, system-wide collapse in maize yields across both districts and distance bands.

The research notes that “the road shortened journeys to depots and reduced vehicle wear, but the 2023/24 season still imposed heavy agronomic penalties in Chibombo, with Nyimba partially buffered,” highlighting that physical access alone could not offset the effects of adverse rainfall distribution, pests and late input delivery.

Qualitative evidence reinforces this interpretation. One male farmer from Chibombo captured the paradox succinctly: “We reached the depot easily this year, but the field didn’t respond. Fertiliser came late and the rains were harsh,” illustrating that while logistics improved, agronomic and climatic conditions undermined potential yield gains. The discussion explicitly links this pattern to Tembo's (2019) argument that “access is only one piece of the productivity puzzle”; timing of inputs, rainfall distribution, pest pressure, and the ability to finance recommended packages ultimately determine how much of the “access dividend” is realised.

From a Spatial Development Theory perspective, the maize results show that the Improved Rural Connectivity Project successfully stretched the ceiling of what is feasible by reducing spatial frictions and underpinning high levels of maize participation in both districts. The spatial pattern of yield changes (more severe collapse in Chibombo and more moderate decline in Nyimba) points to differences in agro-climatic exposure and service environments rather than to any failure of the road intervention itself. From a Sustainable Livelihood Framework viewpoint, the data underline that improved physical capital enabled farmers to maintain their position in the maize market and avoid more drastic area contraction, even as yields fell; area contracted less than yield, suggesting that households chose to stay in the staple crop despite poor returns, possibly to protect food security and maintain access to marketing channels. Maize thus illustrates the core message of this paper: rehabilitated roads made high participation and timely marketing possible but realised productivity in a bad year remained constrained by agronomy, climate and finance.

Sunflower and Soya Bean Diversification Under Improved Connectivity

Sunflower and soya beans provide a window into how rehabilitated roads have shaped cash-crop diversification in Nyimba and Chibombo. Both crops are more marketing-oriented than maize and are strongly influenced by the presence of buyers, processors and reliable transport. Within the Spatial Development Theoretical lens, their expansion or contraction indicates how far improved roads are enabling farmers to plug into higher-value value chains and growth poles. Within the Sustainable Livelihood Framework, continued engagement with these crops reflects households' efforts to strengthen financial capital and manage risk through portfolio diversification, even when seasonal conditions are unfavourable.

The sunflower data paint a complex picture of partial retreat and localised resilience. In Nyimba, participation among households within 2 km of the rehabilitated road declined from 33.5% to 23.2% between 2022/23 and 2023/24 farming seasons, indicating a notable drop in sunflower cultivation in the near-road band (**Table 3**). By contrast, participation in the 2–5 km band remained stable at 50%, suggesting a strong commitment to sunflower among more remote households despite a difficult season. Yields fell across both Nyimba distance bands from 0.38 and 0.31 t/ha to 0.12 and 0.26 t/ha, respectively, pointing to substantial agronomic penalties in 2023/24. In Chibombo, participation was lower overall but yield patterns were more divergent: within 2 km, yields collapsed from 0.24 to 0.01 t/ha, whereas in the 2–5 km band they *rose* from 0.12 to 0.20 t/ha, implying a more favourable outcome for farmers slightly further from the road. The study attributes this contrast to micro-ecological advantages, more timely planting and the avoidance of localised failures in the mid-band, reinforcing the idea that even under uniform infrastructure, agronomy and micro-climate mediate productivity gains.

Table 3: Households Cultivating Sunflower (2022/2023 vs. 2023/2024)

District	Distance to Road	Sample (N)	Season	Cultivation Rate (%)	Average Area (ha)	Average Yield (ton/ha)	ton (yield)	df	p-value
Chibombo	≤ 2 km	78	2022/23	11.5	0.06	0.24			
	≤ 2 km	78	2023/24	7.7	0.04	0.01	110.680	5	< 0.001
	2–5 km	108	2022/23	13.0	0.08	0.12			
	2–5 km	108	2023/24	7.4	0.06	0.20	-40.305	7	< 0.001
Nyimba	≤ 2 km	164	2022/23	33.5	0.10	0.38			
	≤ 2 km	164	2023/24	23.2	0.09	0.12	362.788	37	< 0.001
	2–5 km	22	2022/23	50.0	0.20	0.31			
	2–5 km	22	2023/24	50.0	0.20	0.26	33.566	10	< 0.001

The paired-samples t-tests for sunflower show that yield changes between 2022/23 and 2023/24 are statistically significant in all district–distance groups: Chibombo ≤2 km ($t(5)=110.68$, $p<0.001$) and Nyimba ≤2 km ($t(37)=362.79$, $p<0.001$) experienced large yield declines, while Nyimba 2–5 km shows a smaller but still significant drop ($t(10)=33.57$, $p<0.001$). In contrast, Chibombo 2–5 km recorded a significant increase in sunflower yield, reflected in the negative test statistic ($t(7)=-40.31$, $p<0.001$). These large $|t|$ values indicate that the observed yield changes are many standard errors away from zero and are therefore extremely unlikely to be due to random sampling variation.

As demonstrated in **Table 4**, the soya bean results show an even more distinct commercial profile. Participation declined in most bands: in Chibombo, from 30% to 21% within 2 km and from 33% to 25% in the 2–5 km band; near-road households in Nyimba dropped from 26% to 20%. However, the Nyimba 2–5 km group stands out: participation there remained unchanged at a high 59% (13 of 22 households) across both seasons, despite a severe contraction in yields from 1.03 and 0.86 t/ha in 2022/23 to just 0.14 and 0.12 t/ha in 2023/24. The study interprets this persistence as evidence that households on the remote fringe are deliberately holding their position in the cash-crop market, likely to maintain relationships with buyers and transporters or to preserve a foothold for future price recovery. In Chibombo, soya yields also declined, from around 1.05 and 1.00 t/ha to 0.40 and 0.47 t/ha in the two distance bands, but the contraction was less severe than in Nyimba, hinting at differences in seasonal shocks, extension reach and liquidity for timely inputs.

Table 4: Households Cultivating Soya Beans (2022/2023 vs. 2023/2024)

District	Distance to Road	Sample (N)	Season	Cultivation Rate (%)	Average Area (ha)	Average Yield	Ton (yield)	df	p-value
Chibombo	≤ 2 km	78	2022/23	29.5	0.09	1.05			
	≤ 2 km	78	2023/24	20.5	0.08	0.40	324.319	15	< 0.001
	2–5 km	108	2022/23	33.3	0.07	1.00			
	2–5 km	108	2023/24	25.0	0.04	0.47	377.342	26	< 0.001
Nyimba	≤ 2 km	164	2022/23	26.2	0.15	1.03			
	≤ 2 km	164	2023/24	19.5	0.13	0.14	778.662	31	< 0.001
	2–5 km	22	2022/23	59.1	0.76	0.86			
	2–5 km	22	2023/24	59.1	0.76	0.12	401.600	12	< 0.001

The paired-samples t-tests for soya beans confirm that yield changes between 2022/23 and 2023/24 are statistically significant in all district–distance groups: Chibombo ≤ 2 km ($t(15)=324.32$, $p<0.001$), Chibombo 2–5 km ($t(26)=377.34$, $p<0.001$), Nyimba ≤ 2 km ($t(31)=778.66$, $p<0.001$) and Nyimba 2–5 km ($t(12)=401.60$, $p<0.001$). The very large $|t|$ values indicate that the observed declines in soya yields are many standard errors away from zero, making it extremely unlikely that these differences arise from random sampling variation. In other words, across all four groups, the 2023/24 season produced a statistically robust and substantial contraction in soya productivity.

These patterns underscore the distinction between participation and productivity in high-value crops. The sunflower and soya data show that rehabilitated roads clearly created or reinforced the possibility of market participation: farmers were willing and able to stay in oilseed and legume value chains, particularly in the remote areas of Nyimba within the 2–5 km belt and among Chibombo farmers linked to processors along the corridor. Yet realised yields were overwhelmingly shaped by agronomic and financial conditions. As the research notes, “the data highlight that roads created the possibility of participation, but realised yield depended on agronomy and finance,” and the divergence between districts “underscores the importance of considering local context and specific challenges in agricultural development.” From a Sustainable Livelihood Theory perspective, farmers’ decision to ride out a bad agronomic year while maintaining a presence in sunflower and soya reflects a portfolio logic: they are using improved physical access to keep options open for medium-term income, even when short-term returns are poor.

Interpreted through the Spatial Development Theory, the spatial pattern of diversification suggests emerging corridor effects. In Nyimba, increased or sustained engagement in sunflower and soya along rehabilitated roads indicates that previously peripheral producers are being drawn into oilseed and legume markets that were previously costly to reach. In Chibombo, stronger soya cultivation in the 2–5 km band and the reported return of buyers from Lusaka reflect the growth-pole dynamics associated with improved connectivity: processors and aggregators reinstate or expand their catchment areas once roads become reliable. At the same time, the severe yield collapses in some bands demonstrate that infrastructure stretches the ceiling of feasible diversification but does not remove the floor set by climate, pests and input timing. Sunflower and soya thus reinforce the central conclusion of this paper: Improved Rural Connectivity Project roads have enabled and stabilised participation in commercial crops, but sustained productivity gains require complementary support in agronomy, finance and risk management.

Groundnuts and Cross-crop Synthesis

Groundnuts provide a useful final lens on how rehabilitated roads have interacted with crop-specific agronomy and local contexts. As both food and cash crop, groundnuts sit somewhere between maize (staple) and oilseeds/soya (strongly commercial), and are sensitive to soil fertility, pest pressure and rainfall timing. The survey results indicate a mixed pattern across districts and distance bands. In Chibombo, participation in groundnut production declined between 2022/23 and 2023/24 in both the ≤ 2 km and 2–5 km bands, and average yields fell accordingly, consistent with farmers’ descriptions of a poor season and late or inadequate input use (Table 5). In Nyimba, by contrast, the picture is more differentiated: some near-road producers reduced groundnut area or reported lower yields in 2023/24, but households in the 2–5 km band experienced more stable or even improving yields, suggesting that micro-climatic and soil conditions, as well as localised extension support, helped buffer the crop from wider seasonal stress in certain locations.

The paired-samples t-tests for groundnuts show that yield changes between 2022/23 and 2023/24 are statistically significant in all district–distance groups (Table 5): Chibombo ≤ 2 km ($t(11)=65.67$, $p<0.001$), Chibombo 2–5 km ($t(19)=386.15$, $p<0.001$) and Nyimba ≤ 2 km ($t(44)=417.45$, $p<0.001$) experienced significant yield declines, while Nyimba 2–5 km recorded a significant increase ($t(5)=-36.37$, $p<0.001$). The large magnitudes of these $|t|$ statistics indicate that the observed yield changes are many standard errors away from zero and therefore extremely unlikely to be due to chance. Taken together with the maize, sunflower and soya results, these tests provide strong statistical confirmation that 2023/24 brought a major, uneven shock to crop productivity across districts and distance bands despite improved road access.

Table 5: Households Cultivating Groundnuts (2022/2023 vs. 2023/2024)

District	Distance to Road	Sample (N)	Season	Cultivation Rate (%)	Average Area (ha)	Average Yield (ton/ha)	Ton (yield)	df	p-value
Chibombo	≤ 2 km	78	2022/23	19.2	0.04	0.26			
	≤ 2 km	78	2023/24	15.4	0.03	0.17	65.666	11	< 0.001
	2–5 km	108	2022/23	23.1	0.04	0.47			
	2–5 km	108	2023/24	18.5	0.04	0.04	386.154	19	< 0.001
Nyimba	≤ 2 km	164	2022/23	30.5	0.06	0.35			
	≤ 2 km	164	2023/24	27.4	0.06	0.05	417.447	44	< 0.001
	2–5 km	22	2022/23	36.4	0.04	0.54			
	2–5 km	22	2023/24	27.3	0.03	0.61	-36.366	5	< 0.001

From a livelihood’s perspective, groundnuts appear to serve as a flexible component of farmers' crop portfolios. Focus group discussions in Nyimba suggested that some households maintained or increased groundnut cultivation because the crop “still gives something even when maize fails,” while others reduced their groundnut area to concentrate scarce labour and inputs on maize and soya in a bad year. This behaviour aligns with recent evidence that smallholders adjust crop mix and input intensity in response to both climate signals and market expectations, using legumes as a partial hedge against staple crop failure (Nakamura et al., 2020). In Chibombo, where the 2023/24 season was particularly harsh, the contraction in groundnut participation and yields reinforces the conclusion drawn from maize, sunflower and soya: even where roads have improved, production decisions and outcomes are strongly shaped by seasonal shocks and liquidity constraints.

Taken together, the four crop stories (maize, sunflower, soya beans and groundnuts) underline the central argument of this paper. First, rehabilitated rural roads have clearly expanded participation: land is widely owned; farmers in both Nyimba and Chibombo have been able to remain engaged in staple and commercial crops; and producers in previously more isolated zones (notably the 2–5 km band in Nyimba) have sustained their involvement in sunflower, soya and groundnuts despite adverse conditions. Second, roads have enabled land activation and diversification by lowering the cost of moving inputs and outputs and making it feasible to cultivate previously underused plots or to invest in higher-value crops when buyers and processors are within reach.

However, the crop-level yield dynamics, especially the sharp maize and soya contractions in 2023/24 and the uneven groundnut and sunflower responses, make clear that productivity remains heavily constrained by climate, agronomy and finance. This resonates with recent findings that while rural roads raise the *potential* for higher productivity and commercialisation, their actual impact is contingent on seasonal conditions and access to complementary services, including timely inputs, extension and risk management instruments (Gebresilasse, 2023).

In Spatial Development Theory terms, Improved Rural Connectivity Project roads have raised the *ceiling* of feasible productivity by integrating Nyimba and Chibombo more closely into regional markets. In terms of Sustainable Livelihood Framework, they have strengthened physical capital and helped households maintain a foothold in key value chains. Yet without parallel investments in agronomic support, climate resilience and farmer finance, the productivity benefits of improved roads will continue to be partial, volatile and unevenly distributed across crops, locations and social groups.

Interpreting Productivity Impacts Through Spatial Development Theory and Sustainable Livelihood Framework

The crop-by-crop analysis confirms that the Improved Rural Connectivity Project road rehabilitation has altered the landscape of agricultural production in Nyimba and Chibombo, but in ways that are more about feasible potential than guaranteed outcomes. For maize, roads have helped sustain high participation and stabilised access to depots and markets, even in a very poor season, yet yields collapsed in 2023/24, especially in Chibombo, due to a combination of irregular rainfall, late fertiliser delivery and pest pressure. For sunflower and soya beans, roads have clearly enabled and stabilised participation in commercial value chains, particularly in the 2–5 km belt of Nyimba and in parts of Chibombo served by processors, but yields again reflected agronomic and financial constraints (**Table 6**) more than connectivity alone. Groundnut outcomes add a further layer of nuance, with micro-climatic and soil differences leading to localised yield resilience in certain Nyimba locations, while Chibombo producers experienced more generalised declines.

Table 6: Are credit facilities now being provided in your community after the road project?

District	Distance to the new road		Frequency	Percent
Chibombo	≤ 2 km	No	64	82.1
		Yes	14	17.9
		Total	78	100
	2–5 km	No	103	95.4
		Yes	5	4.6
		Total	108	100
Nyimba	≤ 2 km	No	161	98.2
		Yes	3	1.8
		Total	164	100
	2–5 km	No	21	95.5
		Yes	1	4.5
		Total	22	100

The credit-access data reinforce this interpretation of roads as expanding potential rather than guaranteeing outcomes. Despite the Improved Rural Connectivity Project, only a small minority of communities report new credit facilities: in Chibombo just 17.9% of households within 2 km of the road and 4.6% in the 2–5 km band say credit is now available, while access in Nyimba is even more constrained, at 1.8% and 4.5% respectively. In other words, even where farmers can now reach depots and buyers more easily, most still operate without local formal finance, limiting their ability to purchase fertiliser on time, invest in better seed or absorb climate shocks. This pattern helps explain why maize, sunflower, soya and groundnut yields remain highly volatile and often disappointing: improved connectivity has altered the physical and market landscape, but persistent liquidity constraints mean that many households cannot turn that new access into consistent productivity gains.

Interpreted through Spatial Development Theory, these patterns suggest that the Improved Rural Connectivity Project roads have raised the ceiling of what is spatially and logistically feasible. By reducing travel times and transport costs, especially in Nyimba, they have brought farmers into closer functional proximity to depots, input suppliers and buyers, supporting higher levels of maize engagement and entry or continuation in sunflower and soya value chains. This aligns with recent findings that rural roads can catalyse agricultural growth and commercialisation, particularly when they connect previously marginalised areas to dynamic market centres (Gebresilasse, 2023; Liu and Wen, 2025). At the same time, the stark yield contractions in 2023/24 farming

season, despite better access, underscore that spatial convergence in opportunity does not automatically translate into convergence in outcomes when climatic and market risks intensify.

From a Sustainable Livelihoods perspective, improved roads have strengthened physical capital and, to some extent, financial capital, by enabling continued participation in staple and commercial crops and by improving the logistics of input and output movements. However, the degree to which farmers converted this physical capital into realised productivity gains was constrained by weaknesses in natural capital (rainfall variability and soil moisture), financial capital (liquidity for timely input purchases) and human capital (access to agronomic advice) (Kumar et al., 2023; Natarajan et al., 2024). Households with stronger asset portfolios (like land, livestock, intermediate transport and social ties to buyers) were better able to use the improved roads to maintain or adjust their crop portfolios in the face of a bad season. Poorer, more exposed farmers often found that “the road helped us reach the depot, but the field did not respond,” as one Chibombo respondent put it, encapsulating the “necessary but not sufficient” nature of road investments for agricultural productivity in risk-prone smallholder systems.

CONCLUSION AND POLICY IMPLICATIONS

This paper has examined how rural road rehabilitation under the Improved Rural Connectivity Project has influenced agricultural productivity and resilience among small-scale farmers in Nyimba and Chibombo districts of Zambia. Focusing on land ownership and activation, cropping patterns and yields for maize, sunflower, soya beans and groundnuts over two recent seasons, the analysis shows that improved roads have expanded the ability of farmers to participate in staple and commercial crop production and to bring underused land into cultivation, particularly in more historically peripheral areas such as Nyimba. At the same time, the results demonstrate that yield outcomes are strongly conditioned by agronomic and climatic factors, as well as by access to finance and inputs: in the adverse 2023/24 season, where maize and soya yields fell sharply in both districts despite better physical access to depots and markets, and performance of sunflower and groundnuts was highly uneven across distance bands and micro-ecologies.

Taken together, the findings support three core conclusions. First, rehabilitated rural roads raise the feasible ceiling of smallholder productivity by reducing spatial friction, lowering transport costs and enabling land activation, diversification and sustained participation in multiple value chains. This is consistent with recent global and African evidence that roads are a critical enabling factor for agricultural intensification and commercialisation (Udeuhele & Eze, 2022; Gebresilas, 2023). Second, the actual realised productivity gains remain partial, volatile and sensitive to climate and input system performance, as illustrated by the sharp yield contractions in 2023/24 despite improved access. Third, the benefits of improved roads are unevenly distributed across districts, distance bands and socio-economic groups, reflecting both the geography of markets and processing facilities and the differentiated asset bases and risk exposures of small-scale farmers (Tembo, 2019; Natarajan et al., 2024).

Policy Implications

For food policy and rural development strategy in Zambia, these results imply that rural road investments should be conceived as a necessary foundation for productivity growth, but always embedded within a broader package of complementary interventions.

Integrate roads with input and extension systems. To support agricultural development, roads should be integrated with input and extension systems. This should involve planning fertiliser, seed and agro-chemical supply chains around rehabilitated corridors, focusing on timeliness and price. Strengthening extension and advisory services along improved rural roads is also critical, particularly for drought-tolerant varieties, soil fertility and pest control (Gebresilas, 2023). The Ministry of Agriculture and Road Development Agency should lead implementation, collaborating with fertiliser and seed companies, farmer cooperatives and other partners. Resources should be allocated for additional extension officers, logistics and coordination meetings. Technical resources like agronomic training materials and mapping tools must be developed and MOUs established with major fertiliser suppliers and seed companies to prioritise IRCP routes. Success would be measured through indicators such as proximity of agro-dealers to IRCP corridor communities, timely receipt of

fertiliser and seed by farmers, frequency of extension contacts, adoption of drought-tolerant varieties and farmer satisfaction with input availability.

Target climate resilience alongside connectivity. Climate resilience and connectivity can be simultaneously enhanced by combining road rehabilitation with climate-smart agriculture support. This may include promoting drought-tolerant varieties, conservation agriculture and small-scale water harvesting/irrigation (Nakamura et al., 2020). Potentially, roads can facilitate rapid distribution of relief inputs and advisory support during bad seasons. The Ministry of Agriculture should lead implementation, collaborating with the Ministry of Green Economy and Environment, Disaster Management and Mitigation Unit, including partners like Zambia Meteorological Department and NGOs promoting climate-smart agriculture. Key resources should include funding for demonstration plots, irrigation kits and water harvesting structures, as well as Climate Smart Agriculture-trained extension staff and community facilitators. An early warning and advisory dissemination system linked to roadserved hubs should also be established. Success indicators may include hectares under conservation agriculture, functioning water harvesting schemes, timely climate advisories, and reduced variability in yields over time in IRCP-served areas.

Expand rural finance and liquidity along road corridors. Rural finance and liquidity can be expanded along road corridors by developing tailored financial products for small-scale farmers, such as input credit, warehouse receipt systems and savings groups. Partnerships between financial institutions, agro-dealers, and farmer organisations must be encouraged. The Ministry of Finance & National Planning should lead implementation, collaborating with the Ministry of Agriculture, Citizens Economic Empowerment Commission and partners like commercial banks, microfinance institutions and fintech providers. Key resources may include dedicated credit lines, guarantee facilities and seed funding for warehouse receipt systems. Technical support must be provided for product design, digital platforms and capacity building for farmer groups and loan officers. Success indicators may include access to agricultural credit, volume of loans disbursed, functional warehouse receipt centres, loan repayment rates and active savings groups along corridors.

Leverage roads to deepen value-chain linkages. Improved road connectivity can attract processors, aggregators and traders to production zones, deepening value-chain linkages. This can be achieved by supporting inclusive contracts and outgrower schemes for small-scale farmers in newly connected areas, particularly for crops like sunflower, soya and groundnuts. The Ministry of Commerce, Trade and Industry and Zambia Development Agency should lead implementation, collaborating with the Ministry of Agriculture and private sector partners. Key resources should include incentives for processors, facilitation of land and infrastructure, contract templates and market information systems. Success indicators include the number of processors established, share of production sold through formal contracts, farm-gate prices, small-scale farmer linkages to buyers and volume of crops marketed through IRCP-linked collection points.

Monitor productivity and resilience, not just kilometres of road. The focus should shift from just kilometres of road to tracking productivity and resilience. This should involve monitoring crop-specific yields, diversification, marketed surpluses and seasonal resilience in IRCP and non-IRCP areas, with data disaggregated by district, distance and gender categories (Pillay, 2023; Natarajan et al., 2024). The Road Development Agency and Zambia Statistics Agency should lead implementation, collaborating with the Ministry of Agriculture and research partners. Key resources may include integrated data systems, panel survey tools and human resources like statisticians and M&E officers. Adequate funds must be allocated for data collection and IT infrastructure. Success indicators include the existence of a national IRCP M&E framework, regular crop-specific yield data and routine reporting on key indicators like yields, diversification and marketed surplus. The use of M&E findings to adjust programme design must also be tracked.

Supplementary Material

The authors declare that all the data and materials used in this study are sufficiently included in the manuscript and that no further data or links to the data will be provided.

Authorship Contribution Statement

GM: Writing—review & editing, original draft preparation, visualisation, software implementation, methodology development, investigation, conceptualisation, formal analysis, and data validation.

EMM: Writing—review & editing, supervision, project administration, conceptualisation, methodology oversight and data interpretation.

All authors read, reviewed and approved the final manuscript for publication consideration.

Ethics Approval and Consent to Participate

As part of the PhD study, ethical clearance was obtained from the University of Lusaka Research Ethics Committee. The clearance reference number is FWA000333228-1109/24. Informed consent was sought from all participants, with assurance of confidentiality and voluntary participation. Local leaders were consulted to facilitate community entry and ensure cultural sensitivity.

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Conflicts of Interest

The authors declare that the study was undertaken without any commercial or financial associations that could be perceived as a potential conflict of interest.

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