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Bridging the Yield Gap: A Systems Analysis of the Constraints among Smallholder Maize Farmers in Monze, Zambia

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Abstract

This study analyses the maize yield gap among smallholder farmers in Monze District, Southern Province, Zambia. Using a sequential explanatory mixed-methods design, quantitative data were collected from 398 randomly selected farmers via structured questionnaires and crop-cut yield measurements. Qualitative data included six focus group discussions (n=48), 24 in-depth farmer interviews, and ten key informant interviews. Findings reveal a 64% yield gap (3.35 t/ha), with farmers averaging 1.85 t/ha against an attainable 5.2 t/ha. Decomposition attributed 60% to technology, 25% to efficiency, and 15% to resources. Multiple regression (R^2=0.614, $p<0.001$) identified rainfall adequacy perception, fertilizer application rate, hybrid seed use, extension visits, credit access, and off-farm income as significant determinants. Climate variability (94%), lack of finance (88%), inadequate extension (81%), high input costs (78%), and declining soil fertility (69%) were foremost constraints. Credit access was a powerful enabler: farmers with credit were 3.45 times more likely to use fertilizer and 2.85 times more likely to adopt hybrid seed. The extension system was structurally incapacitated, with an officer-to-farmer ratio of 1:1,200; only 38% of farmers received a visit in the past year, and 53% rated extension services ineffective. Farmers preferred farmer-to-farmer learning (89%), village demonstration plots (84%), and locally tailored interventions (84%), with 73% willing to adopt improved practices given financial support. The study proposes a five-component intervention framework: (i) Climate-Smart Agriculture Promotion; (ii) Improved Financial Inclusion; (iii) Reformed Extension Service Delivery; (iv) Site-Specific Soil Fertility Management; and (v) Market Infrastructure and Access. It concludes that bridging Monze's maize yield gap requires a fundamental reimagining of the agricultural knowledge and innovation system, placing farmers at the centre of a participatory, adequately-resourced, context-specific process of sustainable intensification.

Keywords: Yield Gap, Technology Adoption, Smallholder Farmers, Maize Farming Systems, Climate Variability, Extension Services, Monze District, Zambia

1. Introduction

1.1 Global Food Security and the Challenge of Sustainable Intensification

Global food security is a major 21st-century challenge. With the population projected to exceed 9.7 billion by 2050, agricultural systems must transform to meet rising demand without worsening environmental degradation [1]. This issue is most acute in sub-Saharan Africa (SSA), where population growth is high and agricultural productivity has consistently lagged [2]. Enhancing productivity on existing farmland, known as sustainable intensification, is critical to averting food insecurity and reducing pressure on fragile ecosystems [3].

The challenge of feeding a growing global population is compounded by the fact that the most rapidly growing populations are concentrated in regions where agricultural productivity is already under severe stress. Sub-Saharan Africa, in particular, faces a convergence of demographic, climatic, and economic pressures that make the transformation of its agricultural systems both urgent and complex. The region's population is projected to double by 2050, yet its agricultural yields remain the lowest in the world, creating a widening gap between food demand and domestic production capacity. This divergence between population growth and agricultural productivity represents one of the defining challenges of the 21st century, with profound implications for food security, political stability, and environmental sustainability.

The global food system currently produces enough food to feed the world's population, yet approximately 828 million people

remain chronically undernourished, with the majority residing in sub-Saharan Africa and South Asia [2]. This paradox of plenty amidst scarcity underscores the deeply unequal distribution of food and the structural failures that prevent food from reaching those who need it most. In sub-Saharan Africa, the situation is particularly acute: not only is the region home to the highest prevalence of undernourishment, but it also has the highest population growth rate, meaning that the absolute number of food-insecure people continues to rise even as agricultural production increases. This dynamic creates a race between food production and population growth that the region is currently losing, with profound implications for human welfare, political stability, and environmental sustainability.

The concept of sustainable intensification has emerged as a central organizing principle for addressing this challenge. Sustainable intensification refers to the process of increasing agricultural productivity on existing farmland while simultaneously reducing environmental impact and enhancing the resilience of farming systems [3]. This approach recognizes that the traditional strategy of agricultural expansion, clearing forests and grasslands to bring new land into production, is no longer viable, both because the environmental costs are too high and because the supply of suitable land is increasingly limited. Instead, sustainable intensification focuses on increasing the efficiency with which land, water, nutrients, and labour are used, thereby producing more food from the same or less land while reducing the negative environmental externalities associated with agricultural intensification.

1.2 The Yield Gap Concept: Definitions and Dimensions

A key analytical framework is the yield gap: the difference between the biologically attainable crop yield under optimal management and the actual average yield achieved by farmers [4, 5]. Closing yield gaps for major staples is less environmentally costly than agricultural expansion [6]. However, in SSA's smallholder-dominated landscapes, the yield gap reflects deep socioeconomic, institutional, and biophysical constraints that trap farmers in poverty [7]. The yield gap concept has emerged as a powerful diagnostic tool because it moves beyond simple productivity metrics to reveal the structural and systemic factors that prevent farmers from realizing the full potential of their land, labour, and inputs.

The yield gap framework is particularly valuable because it distinguishes between different types of constraints. The technology yield gap reflects the difference between potential yield and the yield achievable with the best available technologies under typical farm conditions. The efficiency yield gap captures the difference between what farmers could achieve with the technologies they currently use if they applied them optimally, and what they actually achieve. The resource yield gap reflects the difference between yields under optimal management with unlimited resources and yields under the resource constraints that farmers actually face. Understanding the relative magnitude of these different gaps is essential for designing effective interventions, as each type of gap requires different types of solutions.

The decomposition of the yield gap into technology, efficiency, and resource components provides a nuanced diagnostic that can inform targeted interventions. If the technology gap is the largest component, it suggests that the primary constraint is the unavailability or inaccessibility of improved technologies, and interventions should focus on making these technologies more available and accessible. If the efficiency gap is the largest, it suggests that farmers already have access to improved technologies but are not using them optimally, and interventions should focus on improving management practices through training and extension. If the resource gap is the largest, it suggests that farmers are constrained by limited land, labour, or capital, and interventions should focus on addressing these structural constraints through credit, land reform, or labour-saving technologies.

1.3 Maize in Zambia: The Sovereign Crop

In Zambia, closing yield gaps is a national imperative. Agriculture employs over half the labour force, especially in rural areas [8]. Maize (*Zea mays* L.) is the sovereign crop, cornerstone of food security, primary staple, and main income source for an estimated 65% of smallholder farmers [9, 10]. Fluctuations in maize productivity directly affect household nutrition, national food reserves, inflation, and political stability [11]. The centrality of maize to Zambia's food system cannot be overstated. It is not merely a crop but a cultural and economic anchor, shaping land use patterns, labour allocation, dietary practices, and social relations across the country. Any disruption to maize production cascades through the entire economy, affecting everything from rural household food security to urban consumer prices to the national trade balance.

The cultural significance of maize in Zambia extends beyond its economic role. Maize is the primary ingredient in *nshima*, the thick porridge that forms the centrepiece of most Zambian meals. The availability and price of maize meal (*mealie meal*) is a politically sensitive issue, with rising prices often triggering public protests and political instability. This political sensitivity means that maize policy is never far from the centre of national politics, with successive governments implementing various interventions, from input subsidies to price controls to export bans, in an attempt to manage the maize economy. Understanding the maize yield gap in Zambia therefore requires attention not only to agronomic and economic factors but also to the political economy within which maize production is embedded.

Recognizing this, successive Zambian governments have invested in agricultural research. Institutions like the Zambia Agricultural Research Institute (ZARI) and private seed companies have released improved technologies: high-yielding, drought-tolerant maize hybrids, region-specific fertilizer blends, and integrated soil fertility management protocols [12, 13]. On-station trials at Mount Makulu Central Research Station show impressive potential, with maize yields frequently reaching 8-10 tons per hectare under optimal management [12, 14]. These investments in agricultural research have produced a rich portfolio of technologies that, if widely adopted and properly implemented, could dramatically transform smallholder productivity. The challenge, however, lies not in the availability of technologies but in their dissemination, accessibility, and suitability to the diverse and constrained conditions under which smallholder farmers operate.

1.4 The Persistent Yield Gap in Zambia

Yet this potential contrasts starkly with smallholder fields.

National average maize yields for smallholders have stagnated between 1.2 and 2.5 tons per hectare over the past decade, only a fraction of attainable yield [15, 16]. This persistent crevasse constitutes a critical national yield gap, undermining food self-sufficiency, perpetuating rural poverty, and necessitating costly food imports [17]. The gap is most pronounced in regions with compounded stresses, such as the Southern Province. The persistence of this gap over decades, despite sustained investment in research and extension, points to fundamental failures in the systems designed to connect research to farmers' fields. It suggests that the problem is not simply one of technology generation but of technology transfer, adaptation, and adoption within complex socio-economic and agro-ecological contexts.

Monze District, a major maize-producing area within the province, serves as a critical microcosm. The maize yield gap here exceeds 70%; farmers realize less than one-third of the crop's viable potential [18]. This gap perpetuates a 'smallholder poverty trap' [19], where low productivity limits marketable surplus, income, and capacity to invest in future inputs, heightening vulnerability to shocks. The poverty trap concept captures the self-reinforcing nature of low productivity: farmers cannot afford the inputs that would increase yields, so they remain poor, and because they remain poor, they cannot afford inputs. Breaking this cycle requires not just technical solutions but integrated approaches that address the multiple dimensions of farmer vulnerability simultaneously.

The poverty trap in Monze District is compounded by the region's vulnerability to climate variability. Southern Province experiences high climatic variability, with frequent droughts and erratic rainfall patterns that make maize production a risky enterprise. Farmers who invest in improved inputs may lose their investment if rainfall fails, while farmers who do not invest may achieve low yields even in good years. This risk-reward calculus creates a rational reluctance to invest in productivity-enhancing technologies, even when farmers are aware of their potential benefits. Understanding and addressing this risk perception is therefore critical to any strategy for closing the yield gap.

1.5 Research Objectives and Significance

This study is motivated by the critical imperative to develop a contextually nuanced, holistic understanding of the maize yield gap in Monze District. The specific objectives were:

1. To estimate the yield gap among smallholder farmers in Monze District using farmer-reported yields relative to regional benchmarks;
2. To determine the relative influence of key socio-economic and agronomic factors on maize yield variability using multiple regression analysis;
3. To evaluate the capacity and effectiveness of existing technology transfer systems;
4. To assess farmer preferences for different types of interventions and extension delivery approaches; and
5. To develop a context-specific intervention framework for policymakers and extension services.

The significance of this study extends beyond Monze District. By providing a rigorous, mixed-methods analysis of the yield gap in a specific context, it offers a template for understanding similar challenges across Zambia and the wider sub-Saharan African region. The study's emphasis on farmer preferences and participatory approaches also reflects a growing recognition that sustainable agricultural intensification must be built on the knowledge, priorities, and agency of farmers themselves, rather than imposed from outside. In this sense, the study contributes not only to the empirical literature on yield gaps but also to the broader conversation about how agricultural research and development can better serve the needs of smallholder farmers.

2. Literature Review

2.1 Conceptual and Theoretical Framework

The conceptual framework for this study is a systems-based analysis of the maize yield gap in Monze District, grounded in the critique of the Linear Model. This framework rejects the Linear Technology Transfer Model [20], which posits a direct, uncomplicated path from research to dissemination, and finally to adoption. The persistence of the yield gap is empirical proof of this model's failure. Instead, this study adopts a Systems Perspective, recognizing that a farmer's decision to adopt a technology and their ability to realize its yield potential is mediated by a complex, interconnected web of factors. The linear model, which dominated agricultural development thinking for much of the 20th century, assumed that if researchers developed improved technologies and extension services disseminated them effectively, farmers would automatically adopt them and productivity would rise. The persistent yield gaps in sub-Saharan Africa, despite decades of investment in research and extension along these lines, demonstrate the inadequacy of this model.

The framework posits that a household's ability to adopt and effectively implement improved agricultural practices is determined by a confluence of explanatory factors grouped into four interconnected clusters:

1. Socio-economic factors (access to credit, input costs, risk perception, land tenure, labour availability);
2. Agronomic and biophysical factors (soil fertility, acidity, pest pressure, rainfall reliability);
3. Institutional and knowledge transfer factors (quality of extension services, access to agro-dealers, membership in farmer groups);
4. External environment (national policies, climate variability, market dynamics).

These factors directly shape the intervening variable, the adoption and implementation of improved practices, which in turn determines the primary outcome variable: the maize yield gap. This multi-level framework recognizes that yield gaps are not simply the result of farmers failing to adopt technologies, but emerge from the interaction of factors operating at different scales, from the household to the national and even global levels.

The socio-economic cluster captures the household-level factors that determine whether farmers have the resources and incentives to invest in improved practices. Access to credit is particularly important because it determines whether farmers can purchase inputs at the beginning of the season, before they have any income from the current crop. Input costs relative to expected output prices determine the profitability of intensification. Risk perception shapes whether farmers are willing to invest in technologies that may fail if rainfall is poor. Land tenure affects whether farmers have the security to invest in long-term soil fertility improvements. Labour availability determines whether households can implement labour-intensive practices like timely planting and weeding.

The agronomic and biophysical cluster captures the soil, water, and pest conditions that determine the potential response to improved management. Soil fertility and acidity are particularly important in Southern Province, where soils are inherently infertile and acidic. Pest pressure, including both insects and diseases, can cause significant yield losses. Rainfall reliability is perhaps the most critical factor, as maize production in Monze is entirely rainfed and highly vulnerable to drought.

The institutional and knowledge transfer cluster captures the formal and informal systems through which farmers access information, inputs, and markets. The quality of extension services determines whether farmers receive timely, relevant advice. Access to agro-dealers determines whether farmers can purchase inputs locally. Membership in farmer groups can facilitate access to information, credit, and markets. These institutional factors mediate between the broader policy environment and individual farmer decisions.

The external environment cluster captures the macro-level factors that shape the context within which farmers operate. National policies, including input subsidy programs and price supports, can significantly affect farmer incentives. Climate variability, including both long-term trends and short-term shocks, affects the predictability of farming. Market dynamics, including both input and output prices, determine the profitability of different production strategies.

This study is anchored in an integrated theoretical framework drawing from four complementary bodies of literature. Yield Gap Theory [4, 5] establishes the core dependent variable and directs estimation methods. Diffusion of Innovations Theory [21] provides a framework for understanding how new agricultural technologies are communicated and adopted or rejected by farmers, informing the evaluation of technology transfer systems. Farming Systems Research [22] emphasizes that farmers operate within biophysical, socioeconomic, and institutional constraints and pursue multiple goals rather than yield maximization alone, informing the development of a context-specific intervention framework. The Sustainable Livelihoods Framework [23, 24] provides a holistic lens to understand how smallholder farmers mobilize assets in the context of vulnerability and transforming structures, guiding the selection of socio-economic factors for regression analysis. The integration of these four theoretical perspectives allows the study to move beyond simplistic explanations of yield gaps and to develop a nuanced understanding of the multiple, interacting factors that constrain smallholder productivity in Monze District.

2.2 Estimating the Maize Yield Gap

The concept of the yield gap has emerged as one of the most influential analytical frameworks in global agricultural development. Defined as the difference between the potential productivity of a crop and the actual productivity achieved by farmers, the yield gap quantifies the untapped capacity of existing agricultural land [4, 5]. With the global population projected to exceed 9.7 billion by 2050, and with limited scope for agricultural expansion without severe environmental consequences, closing existing yield gaps on current farmland is widely regarded as a central strategy for sustainable intensification [6, 25]. The yield gap concept has gained prominence because it offers a way to increase food production without expanding the agricultural frontier, thereby avoiding the biodiversity loss and carbon emissions associated with deforestation and grassland conversion.

The magnitude of maize yield gaps varies enormously across global regions. In North America and Europe, yield gaps are relatively small (10-20%) due to intensive input use, advanced extension systems, and favourable policies [26]. In Asia, yield gaps are moderate (20-40%) in intensive irrigated systems but larger (50-70%) in rainfed upland areas [27]. In sub-Saharan Africa, maize yield gaps are the largest globally, typically ranging from 60% to 85% [28, 27]. In countries such as Zambia, Tanzania, and Mozambique, smallholder yields of 1-2 t/ha are common, while potential yields of 5-9 t/ha are achievable [29, 10]. This global variation in yield gaps reflects differences not only in agro-ecological conditions but also in the institutional, economic, and policy environments that shape farmer incentives and capacities.

In Zambia, van Ittersum *et al*. [28] estimated that the maize yield gap is approximately 70-80%, placing it among the highest in southern Africa. The yield gap is most pronounced in regions with compounded stresses, such as Southern Province, which experiences high climatic vulnerability superimposed on inherently infertile, acidic sandy loam soils [30, 31]. Monze District, a major maize-producing area within the province, serves as a critical microcosm, with Sichoongwe *et al*. [18] estimating that the maize yield gap exceeds 70%. The convergence of climatic vulnerability and soil constraints in Southern Province creates particularly challenging conditions for maize production, making the yield gap in this region especially difficult to close.

A critical measurement challenge is the systematic discrepancy between farmer-reported and measured yields. Across global, African, and Zambian studies, farmers consistently overestimate yields by 30-100% [32, 33, 34, 35]. Reliance on farmer-reported yields without correction systematically underestimates the true yield gap by 10-25 percentage points [7]. This study addresses this gap by adopting a mixed-methods approach that combines farmer-reported yields with physically measured yields using the crop cut method. The crop cut method, which involves harvesting and weighing crops from measured plots, provides a more accurate assessment of actual yields than farmer recall alone. By combining these two approaches, the study is able to cross-validate yield estimates and provide a more robust assessment of the yield gap.

The discrepancy between farmer-reported and measured yields is not merely a methodological issue but reflects deeper cognitive and social processes. Farmers may overestimate yields because they recall good years more vividly than poor years, because they want to present themselves favourably to researchers, or because they genuinely believe their yields are higher than they are. Understanding these biases is important not only for accurate measurement but also for designing interventions that are based on realistic assessments of current productivity and potential.

2.3 Determinants of Yield Variability

The global literature on yield determinants has moved considerably beyond simple input-output models. A comprehensive review by Rong *et al*. [36] establishes that global potential yields for maize stand at 10.4 t/ha, while actual yields lag at just 5.5 t/ha. The review identifies climate, nutrients, moisture, crop varieties, planting dates, and socioeconomic conditions as the most frequently

mentioned yield-limiting factors [36]. Beza *et al*. [37] found that management and edaphic factors are more often considered, but when included, both farm(er) characteristics and socio-economic factors often explain the yield gap. This shift in the literature reflects a growing recognition that yield gaps are not simply technical problems but are embedded in complex social and economic systems.

In sub-Saharan Africa, the yield determination landscape transforms. Giller *et al*. [38] found that current farm sizes in East Africa are structurally inadequate for generating living incomes, but that raising yields to 50% of water-limited potential could enable 92% of households in Rakai to attain a living income. This finding highlights the potential of yield gap closure to transform rural livelihoods, but also underscores the scale of the challenge. Silva *et al*. [39] conducted the first study providing yield gap decomposition for maize in Zambia, finding that the large yield gap was mostly attributed to the technology yield gap, indicating that more efficient production methods are needed. They argued that narrowing efficiency and resource yield gaps through improved crop management could more than double current yields [39].

The finding that the technology yield gap is the largest component in Zambia is particularly significant because it suggests that the primary constraint is not farmer inefficiency but rather the unavailability or inaccessibility of improved technologies. This contrasts with the common assumption that farmers already have access to improved technologies but fail to use them optimally. If the technology gap is indeed the largest component, then interventions should focus on making improved technologies more available and accessible, rather than simply providing training on how to use technologies that farmers already have.

2.4 Technology Transfer Systems and Intervention Frameworks

The challenge of agricultural development has long been framed as a problem of technology transfer. However, despite decades of investment in this architecture, the knowledge divide persists. A comprehensive scoping review by Becerra-Encinales *et al*. [40] found that the evidence advocates for a paradigm shift from traditional linear knowledge transfer to a more encompassing approach that values bidirectional communication, cultural awareness, and the active involvement of local farming communities. This paradigm shift reflects a growing recognition that technology transfer is not simply a matter of moving information from researchers to farmers, but of co-creating knowledge through ongoing dialogue and collaboration.

In Zambia, the Training and Visit (T&V) system, promoted aggressively by the World Bank in the 1980s and 1990s, represents perhaps the most ambitious attempt to construct a technology transfer architecture. Recent analysis confirms that critical system components, adequately trained and equipped extension personnel, remain lacking or are available only during donor-funded project cycles [41]. The FAO's [42] behavioural science integration in Zambia achieved 60% yield increases through lead-farmer training and participatory problem-solving, demonstrating that when transfer is reconceptualised as a behavioural and relational process, outcomes can improve dramatically. The success of the FAO's behavioural science approach suggests that the key to effective technology transfer lies not in more intensive dissemination of information but in understanding and addressing the behavioural and social factors that shape farmer decision-making.

The global literature on intervention frameworks has moved decisively toward integration. Wang *et al*. [43] conducted a second-order meta-analysis of 104 meta-analyses covering 39,162 studies, introducing a 'triple-goal' agrifood framework that enhances food production, soil health, and GHG mitigation simultaneously. They found that diversified systems boosted yields by 19.6% and reduced land use by 19% [43]. In Africa, Manda *et al*. [44] developed an integrated farming systems approach to identifying and assessing context-specific improvements across four Africa RISING countries, recognizing that heterogeneity requires intervention frameworks that can accommodate diversity. The EWA-BELT project [45] created an interregional African belt to promote sustainable intensification through multi-stakeholder approaches. These integrated approaches recognize that sustainable intensification requires simultaneous attention to productivity, environmental sustainability, and social equity, and that solutions must be tailored to the specific conditions of different farming systems.

2.5 Research Gap

The maize yield gap in Zambia is well-established in the scholarly and policy literature. However, this understanding remains largely diagnostic at a macro-level, offering little actionable intelligence for intervention at the localized scales where farming decisions are made. A critical research gap persists: the absence of a holistic, systems-based, and quantitatively rigorous analysis that integrates socio-economic, agronomic, and institutional dimensions to identify precisely why yields lag in a specific context. This study addresses this gap by advancing a novel, integrated approach anchored in Monze District, achieving precision in quantification, establishing a hierarchy of constraints, undertaking a systemic evaluation of institutions, and delivering an actionable synthesis. By combining rigorous quantitative analysis with qualitative insights into farmer preferences and institutional constraints, the study provides a comprehensive understanding of the yield gap that can inform targeted, context-specific interventions.

3. Materials and Methods

3.1 Research Design

This study employed a sequential explanatory mixed-methods design. Phase one was quantitative, involving a survey that collected numerical data on yields, practices, and socioeconomic factors from a large sample of farmers. Phase two was qualitative, involving Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) that were used to explain, deepen, and contextualize the quantitative findings. The sequential explanatory design was chosen because it allows the quantitative findings to be explained and contextualized through qualitative inquiry, providing a more complete understanding of the yield gap than either approach alone could achieve.

The quantitative phase provided the statistical basis for estimating the yield gap, identifying its determinants, and quantifying the relative importance of different constraints. The qualitative phase then explored the reasons behind these patterns, capturing the experiences, perceptions, and preferences of farmers and other stakeholders. This

sequential approach ensures that the qualitative inquiry is grounded in the empirical findings, rather than being conducted in isolation, and that the quantitative findings are interpreted in light of the lived realities of farmers.

3.2 Target Population, Sample Size, and Sampling

The target population comprised 85,000 smallholder farmers in Monze District, Zambia [46]. The sample size was determined using Yamane's formula:

$$n = N1+N(e)2n=1+N(e)2N \quad (1)$$

Where n = required sample size, N = total population (85,000 farmers), and e = desired margin of error (0.05). At a 95% confidence level, this yielded a sample of 398 respondents. For the qualitative component, a purposive sub-sample of 24 farmers was selected (12 high-yield, 12 low-yield), six focus group discussions were conducted (8 participants each), and ten key informant interviews were held with extension officers, input dealers, and community leaders. A multi-stage sampling approach was employed: purposive selection of Monze District, simple random selection of ten agricultural camps, and systematic random sampling within each camp.

The multi-stage sampling approach was designed to ensure representation across the diversity of farming conditions within Monze District. The purposive selection of Monze District was based on its status as a major maize-producing area with a documented high yield gap. The random selection of ten agricultural camps ensured geographic spread across the district, capturing variation in rainfall, soil conditions, and market access. The systematic random sampling within each camp ensured that the sample was representative of the farming population in each camp, avoiding the biases that could arise from convenience sampling.

The purposive sub-sample of 24 farmers for in-depth interviews was stratified by yield level to ensure that the study captured the experiences of both high-yielding and low-yielding farmers. This stratification allows for comparison between the two groups, identifying the factors that distinguish successful farmers from those who are struggling. The focus group discussions brought together farmers from similar backgrounds to discuss shared challenges and potential solutions, while the key informant interviews provided insights from those who work directly with farmers, including extension officers, input dealers, and community leaders.

3.3 Research Instruments and Data Analysis

Four instruments were utilized: (i) a structured questionnaire capturing socio-demographic data, yield estimates, agronomic practices, extension service access, and intervention preferences; (ii) a key informant interview guide; (iii) a focus group discussion guide; and (iv) a secondary data collection sheet. Quantitative data were analyzed using Stata software. Descriptive statistics summarized key characteristics. Multiple linear regression identified factors significantly associated with the maize yield gap. Logistic regression examined binary outcomes such as technology adoption. Yield gap decomposition followed the framework from Silva *et al.* [39]. Qualitative data were subjected to thematic content analysis, with triangulation integrating quantitative and qualitative findings.

The structured questionnaire was designed to capture a comprehensive picture of each farmer's situation, including their demographic characteristics, farm attributes, agronomic practices, access to extension and credit, and preferences for different types of interventions. The questionnaire was pre-tested with a small group of farmers to ensure that the questions were clear and culturally appropriate. The key informant interview guide was designed to elicit insights from extension officers, input dealers, and community leaders about the challenges facing farmers and the effectiveness of existing support systems. The focus group discussion guide was designed to facilitate open discussion among farmers about their experiences, challenges, and preferences.

The quantitative analysis proceeded in several stages. First, descriptive statistics were used to summarize the characteristics of the sample and to estimate the yield gap. Second, multiple linear regression was used to identify the factors significantly associated with yield variability. Third, logistic regression was used to examine the determinants of technology adoption. Fourth, yield gap decomposition was used to partition the total yield gap into technology, efficiency, and resource components. The qualitative analysis involved transcribing the interviews and focus group discussions, coding the data to identify key themes, and interpreting the themes in light of the quantitative findings.

3.4 Ethical Considerations

The study was conducted in accordance with ethical principles for research involving human subjects. Informed consent was obtained from all participants after explaining the purpose of the study, the voluntary nature of participation, and the confidentiality of responses. Participants were assured that they could withdraw from the study at any time without penalty. Data were anonymized to protect the identity of individual farmers and key informants. The study received ethical approval from the relevant institutional review board.

3.5 Limitations

Several limitations should be acknowledged. First, the study relied on cross-sectional data, which limits the ability to draw causal inferences. Second, the use of farmer-reported yields, even when supplemented by crop-cut measurements, may be subject to recall bias and social desirability bias. Third, the study was conducted in a single district, which limits the generalizability of the findings to other contexts. Fourth, the qualitative component relied on a purposive sample, which may not be representative of the broader farming population. Despite these limitations, the mixed-methods design and the triangulation of quantitative and qualitative data provide a robust basis for understanding the yield gap in Monze District.

4. Results and Discussion

4.1 Socio-Demographic Profile and Farm Attributes

The survey of 398 smallholder farmers revealed a predominantly male (62%), middle-aged population, with over 60% concentrated in their prime productive years. Marital status showed 66% married. Education levels were

modest, with 70% having at most a primary education. Crop farming engaged 60% of respondents, while 35% practiced mixed farming. Land ownership was favourable, with 60% owning their land. The farming workforce was seasoned, with 55% having more than a decade of experience.

The predominance of male farmers in the sample reflects the broader gender dynamics of Zambian agriculture, where men are more likely to be identified as the primary decision-makers for maize production, even though women often contribute significantly to labour. The middle-aged concentration of the sample suggests that farming is primarily pursued by those in their productive years, with younger people potentially migrating to urban areas in search of other opportunities. The modest education levels reflect the historical underinvestment in rural education in Zambia, which has implications for the types of extension approaches that are likely to be effective.

Farm size averaged 2.8 hectares (range: 0.5-5.0 ha), with maize occupying 2.1 hectares on average. Fertilizer application showed substantial heterogeneity: D-compound averaged 124.3 kg/ha (range: 0-300 kg/ha) and urea averaged 87.1 kg/ha (range: 0-250 kg/ha). Seed rates averaged 22.4 kg/ha. Labour inputs averaged 45.6 person-days per hectare (range: 12-120). Input expenditure averaged ZMW 3,850 per hectare (range: ZMW 500-9,200).

The average farm size of 2.8 hectares is typical for smallholder farms in Zambia, but the range from 0.5 to 5.0 hectares indicates significant heterogeneity. The fact that maize occupies an average of 2.1 hectares means that maize is the dominant crop for most farmers, underscoring its importance for food security and income. The wide variation in fertilizer application rates, from 0 to 300 kg/ha for D-compound and 0 to 250 kg/ha for urea, suggests that some farmers are applying little or no fertilizer while others are applying substantial amounts. This heterogeneity is important because it means that interventions need to be tailored to different types of farmers, rather than assuming a uniform approach.

Table 1: Categorical Farm Attributes

Variable	Category	Frequency	Percentage
Seed Type	Hybrid	247	62%
	OPV	72	18%
	Recycled/Local	80	20%
Fertilizer Use	Yes	310	78%
	No	88	22%
Soil Conservation	Yes	88	22%
	No	310	78%
Credit Access	Yes	111	28%
	No	287	72%
Extension Visit	Yes	151	38%
	No	247	62%
Off-farm Income	Yes	167	42%
	No	231	58%

The finding that 62% of farmers use hybrid seed while 38% use either OPV or recycled seed indicates that hybrid seed adoption is relatively high, but a significant minority of farmers are still using lower-yielding varieties. The fact that 78% of farmers use fertilizer while 22% do not is consistent with the finding that fertilizer use is a key determinant of yield. The low adoption of soil conservation practices (22%) is striking, given that 69% of farmers rated their soil fertility as poor or very poor. The low access to credit (28%) is a critical constraint, given the importance of credit for purchasing inputs. The fact that only 38% of farmers received an extension visit in the past year, and that 42% have off-farm income, underscores the limited reach of formal support systems and the importance of diversified livelihoods for many households.

4.2 Maize Yield, Rainfall Scenarios, and the Yield Gap

The overall mean yield was 1,850 kg/ha (range: 450-4,200 kg/ha). Hybrid seed users averaged 2,150 kg/ha, compared to 1,650 kg/ha for OPV users and 1,250 kg/ha for recycled seed users. Fertilizer users averaged 2,050 kg/ha, while non-users achieved just 1,120 kg/ha. Yields varied dramatically across rainfall conditions: 2,850 kg/ha in good years (+54%), 1,850 kg/ha in typical years, and 1,025 kg/ha in drought years (-45%).

The yield differences between hybrid seed users and recycled seed users are substantial, with hybrid users achieving 72% higher yields than those using recycled seed. Similarly, fertilizer users achieved 83% higher yields than non-users. These differences underscore the importance of both improved seed and fertilizer for increasing productivity. However, the fact that even hybrid seed users average only 2,150 kg/ha, far below the attainable potential of 5.2 t/ha, indicates that seed and fertilizer alone are not sufficient to close the yield gap. Other factors, including rainfall, soil conditions, and management practices, also play critical roles.

The dramatic variation in yields across rainfall conditions highlights the vulnerability of maize production to climate variability. In drought years, yields drop by 45% compared to typical years, while in good years they increase by 54%. The asymmetry between gains and losses is particularly important: in absolute terms, the loss in drought years (825 kg/ha) nearly matches the gain in good years (1,000 kg/ha). This means that farmers face symmetric downside risks, which rationally discourages investment in productivity-enhancing inputs. If farmers cannot be confident that they will recoup their investments in good years, they may be reluctant to make those investments at all.

Table 2: Maize Yield Summary Statistics

Yield Measure	Mean (kg/ha)	SD	Minimum	Maximum
All farmers	1,850	890	450	4,200
Hybrid seed users	2,150	780	850	4,200
OPV users	1,650	520	900	2,800
Recycled seed users	1,250	480	450	2,100
Fertilizer users	2,050	820	750	4,200
Non-fertilizer users	1,120	510	450	2,300

The standard deviations in the yield data are substantial, indicating wide variation in yields among farmers within each category. For example, among hybrid seed users, yields range from 850 to 4,200 kg/ha, with a standard deviation of 780 kg/ha. This variation suggests that factors other than seed type, such as soil conditions, rainfall, management practices, and labour availability, also strongly influence yields. The fact that some farmers achieve yields close to the attainable potential while others achieve much lower yields indicates that there is significant room for improvement even among farmers who are already using improved technologies.

The attainable potential yield was 5.2 t/ha (from ZARI trials). Current farmer average yield was 1.85 t/ha, creating an absolute gap of 3.35 t/ha and a percentage yield gap of

64%. Following Silva *et al*. [39], this gap was decomposed into technology gap (60%), efficiency gap (25%), and resource gap (15%).

The finding that the technology gap accounts for 60% of the total yield gap is particularly important. It suggests that the primary constraint is not that farmers are using technologies inefficiently, but that they lack access to the technologies that would allow them to achieve higher yields. This challenges the common assumption that farmers already have access to improved technologies but simply fail to use them optimally. Instead, it suggests that improved varieties, water-harvesting techniques, and appropriate input packages are either unavailable, unaffordable, or inaccessible to the majority of farmers.

Table 3: The Yield Gap and Decomposition

Metric	Value
Attainable potential yield	5.2 t/ha
Current farmer average yield	1.85 t/ha
Absolute yield gap	3.35 t/ha
Percentage yield gap	64%
Technology Gap	2.01 t/ha (60%)
Efficiency Gap	0.84 t/ha (25%)
Resource Gap	0.50 t/ha (15%)

The decomposition of the yield gap into technology, efficiency, and resource components provides a nuanced diagnostic that can inform targeted interventions. The technology gap, which accounts for 60% of the total gap, suggests that interventions should focus on making improved technologies more available and accessible to farmers. This could include expanding the availability of improved seed, fertilizer, and other inputs, as well as reducing their cost through subsidies or credit programs. The efficiency gap, which accounts for 25% of the total gap, suggests that even farmers who have access to improved technologies could increase their yields through better management practices, such as timely planting, optimal plant density, and integrated soil fertility management. The resource gap, which accounts for 15% of the total gap, reflects the constraints imposed by limited land, labour, and capital, which may be more difficult to address through direct interventions.

4.3 Ranking of Constraints and Determinants of Yield Variability

Participatory ranking identified climate variability (94%), lack of access to finance (88%), inadequate extension visits (81%), high input costs (78%), and declining soil fertility (69%) as the top five constraints.

The ranking of constraints provides a clear picture of the challenges facing farmers in Monze District. Climate variability is the most frequently cited constraint, reflecting the reality that maize production in the district is entirely rainfed and highly vulnerable to drought. The lack of access to finance is the second most cited constraint, underscoring the importance of credit for purchasing inputs. Inadequate extension visits is the third most cited constraint, indicating that farmers are not receiving the support they need to adopt improved practices. High input costs and declining soil fertility round out the top five constraints, highlighting the economic and biophysical challenges that farmers face.

Table 4: Ranking of Constraints

Rank	Constraint	Frequency	Percentage
1	Climate variability / erratic rainfall	374	94%
2	Lack of access to finance / credit	350	88%
3	Inadequate/infrequent extension visits	322	81%
4	High input costs / limited access to inputs	310	78%
5	Declining soil fertility	275	69%
6	Pests and diseases	248	62%
7	Poor market access / output prices	231	58%
8	Labour shortages	195	49%
9	Land tenure insecurity	159	40%
10	Poor road infrastructure	127	32%

Multiple regression analysis ($R^2 = 0.614$, $p < 0.001$) identified rainfall adequacy perception ($\beta = +0.41$, $p < 0.001$) as the strongest determinant, followed by fertilizer application rate (+0.042, $p < 0.001$), hybrid seed use (+0.38, $p < 0.01$), extension visits (+0.35, $p < 0.01$), credit access (+0.29, $p < 0.05$), and off-farm income (+0.18, $p < 0.05$).

The regression model explains 61.4% of the variation in yields, which is a relatively high R^2 for this type of analysis. The finding that rainfall adequacy perception is the strongest determinant confirms the importance of climate variability as a constraint. The significance of fertilizer application rate, hybrid seed use, extension visits, credit access, and off-farm income all point to the importance of access to inputs, information, and financial resources. The fact that education, age, farm size, and soil conservation were not significant suggests that these factors are less important than access to inputs and information in determining yields.

Table 5: Determinants of Yield Variability

Factor	Coefficient	Significance
Rainfall adequacy perception	+0.41	p<0.001
Fertilizer application rate	+0.042	p<0.001
Hybrid seed use	+0.38	p<0.01
Extension visits in past year	+0.35	p<0.01
Access to credit	+0.29	p<0.05
Off-farm income	+0.18	p<0.05
Education level	+0.09	ns
Age of household head	-0.07	ns
Farm size	+0.11	ns
Soil conservation practice	+0.14	ns

The coefficient for fertilizer application rate (+0.042) indicates that for each additional kilogram of fertilizer applied per hectare, yield increases by 0.042 t/ha (42 kg/ha). Given that the average fertilizer application rate is 124.3 kg/ha for D-compound and 87.1 kg/ha for urea, this suggests that increasing fertilizer application rates could significantly increase yields. However, the fact that many farmers apply little or no fertilizer suggests that access and affordability are major constraints.

4.4 Extension Service Profile and Information Sources

The district has 42 extension officers, yielding a farmer-to-extension officer ratio of 1:1,200, far exceeding the recommended 1:500. Only 38% of farmers received a visit in the past year, averaging 1.7 visits annually. Over half (53%) rated extension services as ineffective or very ineffective. Farmers relied overwhelmingly on other farmers (89%) and radio (76%).

The extension system in Monze District is clearly overstretched, with each extension officer responsible for 1,200 farmers, more than double the recommended ratio of 1:500. The fact that only 38% of farmers received a visit in the past year, and that those who did received an average of only 1.7 visits, indicates that the reach of the extension system is severely limited. The finding that 53% of farmers rated extension services as ineffective or very ineffective suggests that even when farmers do receive visits, the quality of the service is often poor. The reliance on other farmers and radio as sources of information indicates that farmers are filling the gap left by the formal extension system through informal networks and mass media.

Table 6: Farmer Perceptions of Extension Effectiveness

Rating	Percentage
Very ineffective	22%
Ineffective	31%
Neutral	25%
Effective	16%
Very effective	6%

The finding that only 22% of farmers rated extension services as effective or very effective, while 53% rated them as ineffective or very ineffective, indicates a widespread dissatisfaction with the current system. This dissatisfaction is not necessarily a reflection on the individual extension officers, who may be doing their best under difficult circumstances, but rather on the structural limitations of the system, including inadequate staffing, funding, and training.

Table 7: Alternative Information Sources

Source	Percentage Using	Average Ranking (1=most important)
Other farmers / neighbours	89%	1.4
Radio	76%	2.3
Extension officer	62%	2.8
NGO	48%	3.1
Farmer cooperative	39%	3.5
Mobile phone / WhatsApp	34%	3.8
Input supplier	28%	4.2
Television	12%	5.0

The finding that other farmers are the most important source of information, used by 89% of farmers and ranked first in importance, highlights the importance of peer-to-peer learning. Radio is the second most important source, used by 76% of farmers. Extension officers are used by 62% of farmers but ranked third in importance, suggesting that while many farmers have contact with extension officers, the quality or relevance of the information they receive may be limited. The relatively low use of mobile phones and WhatsApp (34%) suggests that there is potential to expand the use of digital technologies for agricultural extension, but that access to these technologies is still limited.

4.5 Preferred Interventions and Extension Delivery Preferences

Farmers' intervention priorities revealed a pragmatic hierarchy: subsidized fertilizer/inputs (92%), reliable credit (78%), drought-tolerant maize seed (71%), better extension training (65%), and irrigation support (58%). Farmers overwhelmingly preferred peer-mediated learning: farmer-to-farmer learning (89%), demonstration plots (84%), and local farmer trainers (78%). Conventional extension visits ranked lowest (38%).

The finding that subsidized fertilizer/inputs is the top priority for 92% of farmers reflects the importance of input costs as a constraint. The second priority, reliable credit (78%), is closely related, as credit is often necessary to purchase inputs. The third priority, drought-tolerant maize seed (71%), reflects the importance of climate variability as a constraint. The fourth priority, better extension training (65%), and the fifth priority, irrigation support (58%), round out the top five. The fact that farmers prefer farmer-to-farmer learning, demonstration plots, and local farmer trainers over conventional extension visits suggests that they value practical, hands-on learning opportunities that are grounded in local experience.

Table 8: Preferred Interventions & Extension Delivery

Rank	Intervention	Percentage
1	Subsidized fertilizer/inputs	92%
2	Reliable access to credit	78%
3	Drought-tolerant maize seed	71%
4	Better extension training	65%
5	Irrigation support	58%
6	Improved market access	52%
7	Soil fertility management	48%
	Extension Delivery Preferences	
1	Farmer-to-farmer learning	89%
2	Demonstration plots	84%
3	Local farmer trainers	78%
4	Radio programs	65%
5	Mobile phone/SMS advisory	52%
6	Conventional extension visits	38%

The finding that only 38% of farmers preferred conventional extension visits, while 89% preferred farmer-to-farmer learning, 84% preferred demonstration plots, and 78% preferred local farmer trainers, has important implications for the design of extension services. It suggests that the current model of extension, which relies primarily on visits from extension officers, is not well-aligned with farmer preferences. Instead, farmers prefer approaches that are more participatory, practical, and grounded in local experience.

4.6 Inferential Statistics

Correlation analysis showed yield was most strongly correlated with fertilizer application ($r = 0.62$, $p < 0.001$), followed by hybrid seed use ($r = 0.45$, $p < 0.01$), extension visits ($r = 0.41$, $p < 0.01$), and credit access ($r = 0.38$, $p < 0.05$). Logistic regression revealed that farmers with credit access were 3.45 times more likely to use fertilizer and 2.85 times more likely to adopt hybrid seed.

The correlation coefficients confirm the importance of fertilizer, hybrid seed, extension visits, and credit access for yields. The logistic regression results provide further evidence of the importance of credit access, showing that farmers with credit are significantly more likely to use fertilizer and hybrid seed. This suggests that credit access is a cross-cutting enabler that facilitates the adoption of multiple improved technologies.

Table 9: Logistic Regression-Technology Adoption

Variable	Odds Ratio (Hybrid Seed)	Odds Ratio (Fertilizer)
Credit access	2.85**	3.45**
Extension visit	2.48*	2.12
Off-farm income	1.85	2.78**
Education (primary+)	1.42	1.35
Farm size (>2 ha)	1.28	1.19

*p<0.05, **p<0.01

The finding that farmers with credit access are 3.45 times more likely to use fertilizer and 2.85 times more likely to adopt hybrid seed underscores the importance of financial inclusion for agricultural intensification. Without access to credit, farmers cannot purchase the inputs they need to increase their yields, trapping them in a cycle of low productivity and poverty. Expanding access to credit, whether through formal financial institutions, mobile money, or community-based savings groups, is therefore a critical component of any strategy to close the yield gap.

4.7 Qualitative Findings: Farmer Voices & Experiences

The qualitative component of the study provided rich insights into the lived experiences of farmers and the structural constraints they face. Several themes emerged from the focus group discussions and in-depth interviews.

Theme 1: Climate Uncertainty and Risk Aversion

Farmers consistently emphasized the unpredictability of rainfall as the primary challenge they face. As one farmer explained: "We used to know when the rains would come, but now we cannot predict. Last year, we planted in November and the rains stopped in January. Those who had invested in fertilizer lost everything. This year, I am afraid to use fertilizer because I don't know if the rains will come."

This quote captures the rational risk aversion that characterizes many farmers' decision-making. When farmers cannot predict whether rainfall will be adequate, investing in productivity-enhancing inputs becomes a gamble that many are unwilling to take. This finding is consistent with the quantitative result that rainfall adequacy perception is the strongest determinant of yield variability.

Theme 2: Financial Exclusion & the Credit Constraint

The lack of access to credit emerged as a critical constraint across all focus groups. Farmers described being trapped in a cycle where they could not afford inputs at the beginning of the season, which led to low yields, which in turn left them with insufficient income to purchase inputs for the next season. As one farmer put it: "We know what we need to do to get better yields. We need fertilizer, hybrid seed, and timely planting. But where will we get the money? The banks say we have no collateral. The government subsidies come late and only reach some of us. We are stuck."

The finding that only 28% of farmers have access to credit, combined with the logistic regression results showing that credit access is a powerful enabler of technology adoption, underscores the importance of financial inclusion as a policy priority.

Theme 3: The Extension Gap and Farmer Innovation

Farmers described the formal extension system as largely absent from their daily reality. Most farmers could not name their extension officer or recall the last time they received a visit. However, farmers did not simply wait for formal extension services; they developed their own informal networks for sharing information and learning from each other. As one farmer explained: "We learn from each other. When someone tries something new and it works, we all want to know about it. We have our own ways of sharing knowledge."

This finding highlights the resilience and agency of farmers, but also the structural failure of the formal extension system. The finding that farmers prefer farmer-to-farmer learning, demonstration plots, and local farmer trainers suggests that the extension system should be reoriented to build on these existing informal networks rather than trying to replace them.

Theme 4: Soil Fertility Decline and the Need for Integrated Management

Farmers consistently reported declining soil fertility as a major challenge. Many described soils that were once productive but had become degraded through continuous maize cultivation without adequate replenishment of nutrients. As one farmer observed: "Our grandparents grew maize without fertilizer and got good yields. Now, even with fertilizer, we don't get the same yields. The soil is tired. We need to find ways to restore it."

This finding points to the need for site-specific soil fertility management that goes beyond simply applying more fertilizer. Integrated soil fertility management, which combines organic and inorganic nutrient sources, conservation agriculture, and agroforestry, may be necessary to restore soil health and sustain productivity over the long term.

Theme 5: Market Access and Price Volatility

Farmers described significant challenges in accessing markets and obtaining fair prices for their produce. Many reported being forced to sell at low prices immediately after harvest because they needed cash, only to see prices rise later in the season. As one farmer explained: "We sell our maize at harvest when the price is low because we need money. Then later, we have to buy mealie meal at a higher price. It feels like we are always losing."

This finding highlights the importance of market infrastructure and access as a component of any strategy to improve smallholder livelihoods. Without better market access and the ability to store and sell when prices are favourable, farmers will continue to be price-takers in markets that are often unfavourable to them.

4.8 Discussion of Key Findings

The finding that Monze District's smallholder maize farmers achieve only 1.85 t/ha against an attainable potential of 5.2 t/ha, giving a yield gap of 64%, positions the district firmly within the sub-Saharan African norm. This aligns closely with van Ittersum *et al.* [28] and with Silva *et al.* [39]. The study's decomposition of the yield gap offers a more nuanced diagnostic: the finding that the technology gap accounts for 60% of the total gap challenges the implicit assumption that farmers already possess the necessary technologies but simply mismanage them. Instead, improved varieties, water-harvesting techniques, and appropriate input packages are either unavailable, unaffordable, or inaccessible to the majority of farmers.

The dramatic rainfall-driven variation in yields, from 2,850

kg/ha in good years to 1,025 kg/ha in drought years, underscores climate vulnerability. The asymmetry between gains in good years (+54%) and losses in drought years (-45%) is particularly telling: in absolute terms, the loss (825 kg/ha) nearly matches the gain (1,000 kg/ha), meaning that farmers face symmetric downside risks that rationally discourage investment in productivity-enhancing inputs. This finding has important implications for the design of risk management strategies, such as weather index insurance or drought-tolerant varieties, which could help farmers manage climate risk and make investments in productivity.

The regression analysis identifies rainfall adequacy perception as the strongest determinant of yield variability. The significance of credit access as a cross-cutting enabler deserves particular attention: farmers with credit access are 3.45 times more likely to use fertilizer and 2.85 times more likely to adopt hybrid seed. The finding that only 28% of farmers have access to credit reveals a financial system that is fundamentally failing smallholder agriculture. The non-significance of education, age, farm size, and soil conservation is noteworthy, suggesting that the quality of extension services, rather than formal education, is the binding constraint on knowledge acquisition, and that intensification, not expansion, is the pathway to closing the yield gap.

The extension system is structurally incapacitated: the officer-to-farmer ratio of 1:1,200 far exceeds the recommended 1:500; only 38% of farmers received a visit in the past year; and 53% rated the service as ineffective. The trust-reach paradox, where farmers trust public extension officers most but rely on them least, suggests that the problem is not credibility but availability and accessibility. The finding that only 18% of farmers had ever provided feedback to extension officers reveals a near-total absence of feedback loops, ensuring that lessons learned from farmer experience are systematically lost.

The five-component intervention framework proposed in this study is grounded in the empirical findings and farmer preferences. Climate-Smart Agriculture Promotion responds directly to climate variability as the dominant constraint (94%). Improved Financial Inclusion addresses the credit constraint that emerged as the most powerful cross-cutting enabler of technology adoption. Reformed Extension Service Delivery responds directly to farmers' expressed preferences for farmer-to-farmer learning, demonstration plots, and local farmer trainers. Site-Specific Soil Fertility Management addresses the finding that 69% of farmers rated their soil fertility as poor or very poor, yet only 22% practice any soil conservation. Market Infrastructure and Access addresses post-harvest losses and weak market linkages that undermine economic incentives to produce a surplus.

The proposed framework is not a blueprint to be imposed from outside but a flexible guide that should be adapted to local conditions through participatory processes. The success of the framework will depend on the extent to which it is owned and driven by farmers themselves, supported by enabling policies and adequate resources. It will also depend on the extent to which different components are integrated and mutually reinforcing, rather than implemented in isolation. For example, expanding access to credit without also improving the availability of inputs and the quality of extension services is unlikely to lead to sustained increases in productivity. Similarly, promoting climate-smart agriculture without addressing the underlying financial constraints that prevent farmers from investing in new practices is unlikely to succeed.

5. Synthesis: A Five-Component Intervention Framework

Based on the empirical findings and farmer preferences, this study proposes a five-component intervention framework for bridging the maize yield gap in Monze District. The framework is designed to be integrated and mutually reinforcing, with each component addressing a critical constraint identified in the analysis.

5.1 Component 1: Climate-Smart Agriculture Promotion

Rationale: Climate variability was identified as the dominant constraint by 94% of farmers, and rainfall adequacy perception was the strongest determinant of yield variability in the regression analysis ($\beta = +0.41$, $p < 0.001$). The dramatic variation in yields across rainfall conditions, from 2,850 kg/ha in good years to 1,025 kg/ha in drought years, underscores the vulnerability of maize production to climate shocks.

Proposed Interventions:

1. **Drought-tolerant maize varieties:** Expand the availability and adoption of drought-tolerant hybrids that can maintain productivity under low-rainfall conditions. These varieties should be tested and adapted to local conditions through participatory variety selection.
2. **Water harvesting techniques:** Promote the adoption of water harvesting techniques, including ripping, potholing, and tied ridges, which can capture and retain rainfall, reducing the impact of dry spells.
3. **Conservation agriculture:** Promote conservation agriculture practices, including minimum tillage, permanent soil cover, and crop rotation, which can improve soil moisture retention and reduce vulnerability to drought.
4. **Climate information services:** Strengthen the provision of seasonal climate forecasts and advisory services, enabling farmers to make informed decisions about planting dates, variety selection, and input use.
5. **Weather index insurance:** Pilot and scale weather index insurance products that can provide farmers with a safety net when rainfall fails, reducing the risk of investing in productivity-enhancing inputs.

5.2 Component 2: Improved Financial Inclusion

Rationale: Lack of access to finance was identified as a constraint by 88% of farmers, and credit access emerged as a powerful cross-cutting enabler of technology adoption. Farmers with credit access were 3.45 times more likely to use fertilizer and 2.85 times more likely to adopt hybrid seed. Yet only 28% of farmers currently have access to credit.

Proposed Interventions:

1. **Expanded rural credit facilities:** Work with financial institutions to expand the availability of credit in rural areas, including through the establishment of rural bank branches and mobile banking services.
2. **Value chain financing:** Promote value chain financing arrangements, where off-takers (e.g., millers, processors) provide inputs on credit to farmers and deduct the cost from the purchase price at harvest.

3. **Community savings groups:** Support the formation and strengthening of community-based savings and loan groups (e.g., Village Savings and Loan Associations), which can provide small-scale credit to farmers who lack access to formal financial institutions.
4. **Mobile money and digital financial services:** Expand access to mobile money and digital financial services, which can reduce transaction costs and increase financial inclusion for smallholder farmers.
5. **Credit guarantee schemes:** Establish credit guarantee schemes that reduce the risk for financial institutions lending to smallholder farmers, who often lack collateral.
6. **Input subsidy program reform:** Reform the existing input subsidy program to ensure timely delivery of inputs, better targeting of the most vulnerable farmers, and integration with credit and extension services.

5.3 Component 3: Reformed Extension Service Delivery

Rationale: Inadequate extension visits were identified as a constraint by 81% of farmers. The extension system is structurally incapacitated, with an officer-to-farmer ratio of 1:1,200 (far exceeding the recommended 1:500), only 38% of farmers receiving a visit in the past year, and 53% rating extension services as ineffective. Farmers overwhelmingly prefer farmer-to-farmer learning (89%), demonstration plots (84%), and local farmer trainers (78%) over conventional extension visits (38%).

Proposed Interventions:

1. **Farmer-to-farmer learning networks:** Establish and strengthen farmer-to-farmer learning networks, where successful farmers are trained as local trainers who can share their knowledge and experience with their peers.
2. **Village demonstration plots:** Establish village-level demonstration plots where farmers can see improved practices in action and learn from hands-on experience.
3. **Local farmer trainers:** Recruit, train, and support local farmer trainers who can provide ongoing advisory services within their communities, complementing the work of formal extension officers.
4. **Information and communication technology (ICT)-enabled extension:** Leverage mobile phones, radio, and other ICT tools to extend the reach of extension services, providing farmers with timely information on weather, markets, and improved practices.
5. **Extension officer training and support:** Invest in the training and support of extension officers, ensuring they have the knowledge, skills, and resources needed to provide effective advisory services.
6. **Feedback mechanisms:** Establish feedback mechanisms that allow farmers to provide input into the design and delivery of extension services, ensuring that services are responsive to farmer needs and preferences.
7. **Performance-based extension:** Introduce performance-based incentives for extension officers, linked to the adoption of improved practices and increases in productivity among the farmers they serve.

5.4 Component 4: Site-Specific Soil Fertility Management

Rationale: Declining soil fertility was identified as a constraint by 69% of farmers, yet only 22% practice any soil conservation. The finding that the technology gap accounts for 60% of the total yield gap suggests that improved soil fertility management technologies are either unavailable or inaccessible to most farmers.

Proposed Interventions:

1. **Soil testing and fertility mapping:** Expand access to soil testing services and develop soil fertility maps that can guide site-specific fertilizer recommendations.
2. **Integrated soil fertility management:** Promote integrated soil fertility management practices that combine organic and inorganic nutrient sources, including the use of compost, manure, and legume rotations.
3. **Fertilizer blending and recommendations:** Work with fertilizer companies to develop and distribute region-specific fertilizer blends that match local soil conditions and crop requirements.
4. **Agroforestry:** Promote agroforestry practices, including the integration of nitrogen-fixing trees and shrubs into farming systems, which can improve soil fertility and provide additional sources of income.
5. **Conservation agriculture:** Promote conservation agriculture practices that improve soil health, including minimum tillage, permanent soil cover, and crop rotation.
6. **Lime application:** Promote the application of agricultural lime to address soil acidity, which is a major constraint in Southern Province.

5.5 Component 5: Market Infrastructure and Access

Rationale: Poor market access and output prices were identified as a constraint by 58% of farmers. Post-harvest losses and weak market linkages undermine economic incentives to produce a surplus, trapping farmers in a cycle of low productivity and poverty.

Proposed Interventions:

1. **Rural road infrastructure:** Invest in rural road infrastructure to improve market access and reduce transportation costs for farmers.
2. **Storage facilities:** Establish community-level storage facilities that allow farmers to store their produce and sell when prices are favourable, rather than being forced to sell immediately after harvest.
3. **Market information systems:** Develop and disseminate market information systems that provide farmers with timely information on prices, demand, and market opportunities.
4. **Farmer cooperatives and aggregation:** Support the formation and strengthening of farmer cooperatives and other forms of aggregation, which can improve farmers' bargaining power and access to markets.
5. **Value addition:** Promote value addition activities, such as maize milling and processing, which can increase the value captured by farmers and create employment opportunities in rural areas.
6. **Contract farming arrangements:** Promote contract farming arrangements between farmers and off-takers, which can provide farmers with guaranteed markets and fair prices.
7. **Post-harvest handling:** Train farmers in improved post-harvest handling practices, including proper drying, shelling, and storage, to reduce losses and improve quality.

5.6 Integration and Implementation

The five components of the intervention framework are

designed to be mutually reinforcing. For example, expanding access to credit (Component 2) without also improving the availability of inputs and the quality of extension services (Component 3) is unlikely to lead to sustained increases in productivity. Similarly, promoting climate-smart agriculture (Component 1) without addressing the underlying financial constraints that prevent farmers from investing in new practices is unlikely to succeed.

Implementation of the framework should be led by the Ministry of Agriculture, in partnership with other government agencies, non-governmental organizations, private sector actors, and farmer organizations. The framework should be adapted to local conditions through participatory processes, ensuring that interventions are tailored to the specific needs and priorities of different farming communities.

Monitoring and evaluation should be integrated into the implementation process, with regular collection of data on adoption rates, productivity, and farmer satisfaction. This data should be used to adapt and refine the intervention framework over time, ensuring that it remains responsive to changing conditions and emerging challenges.

6. Conclusions and Recommendations

This study has demonstrated that Monze District faces a substantial and persistent maize yield gap, driven primarily by climate variability, financial constraints, and institutional failure. The technology transfer system is structurally incapacitated, and farmers rely on informal networks and peer learning to fill the void. The proposed intervention framework, grounded in farmer preferences and empirical evidence, offers a context-specific pathway for bridging the gap. Bridging the maize yield gap in Monze District requires not merely technical fixes but a fundamental reimagining of the agricultural knowledge and innovation system, one that places farmers at the centre of a participatory, context-specific, and adequately resourced process of sustainable intensification. The cost of inaction is continued poverty, food insecurity, and environmental degradation; the cost of action is an investment in Monze District and, by extension, in Zambia's food security and prosperity.

The study's findings have several important implications for policy and practice. First, the dominance of the technology gap in the decomposition of the yield gap suggests that efforts to close the gap must prioritize making improved technologies more available and accessible to farmers. This includes not only expanding the supply of improved seed and fertilizer but also reducing their cost through subsidies, credit programs, and improved market efficiency. Second, the importance of credit access as a cross-cutting enabler of technology adoption suggests that financial inclusion should be a central component of any strategy to close the yield gap. This could include expanding access to formal credit, promoting mobile money and digital financial services, and supporting community-based savings and loan groups. Third, the structural incapacitation of the extension system suggests that fundamental reform is needed to make extension services more responsive to farmer needs and preferences. This could include shifting from a model based on visits from extension officers to a model based on farmer-to-farmer learning, demonstration plots, and local farmer trainers. Fourth, the importance of climate variability as a constraint suggests that climate-smart agriculture practices, including drought-tolerant varieties, water-harvesting techniques, and conservation agriculture, should be promoted. Fifth, the low adoption of soil conservation practices despite widespread recognition of declining soil fertility suggests that site-specific soil fertility management should be prioritized.

The study also highlights the importance of farmer agency and participatory approaches in agricultural development. Farmers are not passive recipients of technology but active agents who make rational decisions based on their assessment of risks, costs, and benefits. Interventions that are imposed from outside without engaging farmers in the design and implementation process are unlikely to succeed. Instead, interventions should be co-created with farmers, building on their knowledge, priorities, and aspirations.

Future research should build on the findings of this study in several ways. First, longitudinal studies that track farmers over multiple seasons could provide insights into the dynamics of yield gap closure and the factors that facilitate or constrain sustained increases in productivity. Second, experimental studies that test different intervention approaches could provide rigorous evidence on what works and what does not. Third, research that explores the gender dimensions of the yield gap could provide insights into how interventions can be designed to benefit both men and women. Fourth, research that examines the scalability of different interventions could provide insights into how successful approaches can be expanded to reach more farmers. Fifth, research that examines the political economy of agricultural policy in Zambia could provide insights into the barriers to implementing the kinds of systemic reforms proposed in this study.

In conclusion, closing the maize yield gap in Monze District is not only a technical challenge but a social, economic, and political one. It requires a fundamental reimagining of the agricultural knowledge and innovation system, one that places farmers at the centre of a participatory, context-specific, and adequately resourced process of sustainable intensification. The cost of inaction is continued poverty, food insecurity, and environmental degradation; the cost of action is an investment in Monze District and, by extension, in Zambia's food security and prosperity. The time for action is now.

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