Soil Fertility Constraints and Gross Margin Sensitivity in Maize Production: Evidence from Smallholder Production Systems in Hwedza District, Zimbabwe

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ABSTRACT

Smallholder maize production in Zimbabwe remains central to food security and rural livelihoods, yet profitability is constrained by soil fertility limitations and yield variability. This study examined farm-level differences in productivity and profitability in Hwedza and Harare, focusing on soil nutrient status, input use and economic outcomes. Ten representative farm soil samples were analysed for soil fertility status using laboratory soil tests, yield measurements, gross margin calculations, and return per dollar invested. Results revealed moderate to strong acidity of pH 4.3-6.0, critically low phosphorus, deficient potassium and patchy calcium and magnesium levels. Laboratory prescriptions recommended substantial corrective inputs, including 300-2000kg/ha dolomitic lime (calcium magnesium carbonate), basal fertiliser, 100-500kg/ha compound D (N:7, P:14, K:7), and top dressing 300-650kg/ha ammonium nitrate 34.5% N. However, farmers applied significantly lower rates, with 30% complementing with cattle manure, reflecting affordability constraints and limited access to inputs. Yield outcomes ranged from 0.93-3.10t/ha, with 80% of the households producing below the gross margin-based break-even yield threshold of 2.16t/ha and a return per dollar invested break-even yield of 2.23t/ha. Gross margins varied sharply from -USD 250.4/ha to +USD 147.67/ha, while returns per dollar invested ranged from -USD 45 to +USD 0.25. Regression analysis confirmed yield as the dominant determinant of profitability. Local studies corroborate these findings, showing that profitability is strongly yield-dependent and that integrated nutrient management combining organic and inorganic inputs improves outcomes. Regional evidence from South Africa, Tanzania and Uganda similarly highlights the importance of resource access, balanced fertilisation, and cooperative structures in achieving sustainable intensification. This study demonstrates that yield optimisation above 2.16t/ha and 2.23t/ha is critical for profitability in smallholder maize systems of Hwedza. Addressing systematic barriers in soil acidity, high input costs, insufficient lime use, and limited fertilisation strategies requires a dual strategy combining agronomy and enabling policies. Agronomic interventions are implemented through lime application, balanced organic and inorganic fertiliser amendments, complemented by enabling policies such as input subsidies, credit schemes and market stabilisation. By bridging technical and economic dimensions, smallholder farmers can achieve higher yields, secure positive margins and sustain profitable returns, thereby strengthening resilience in sustainable smallholder maize production systems in Hwedza.

Keywords: Maize productivity, soil fertility constraints, smallholder, profitability, Integrated soil fertility management (ISFM), yield variability, production cost

INTRODUCTION

The agriculture the backbone of rural households in Zimbabwe, with over 70% (GoZ., 2025) of the population in rural population involved in agriculture. The rural population is dominated by women who make up to 60% of the population (GoZ., 2025). Contributing 11-14% to the GDP (MFIT, 2025), agriculture remains central to food security, exports and rural survival. Rural households in Zimbabwe commonly practice agropastoral

systems where crops and livestock are integrated to create synergies that reduce risk and strengthen food and nutrition security (Musara et al., 2021). These mixed systems use a deliberate livelihood strategy, allowing households to hedge against climate shocks, market fluctuations, and seasonal feed shortages (Musara et al., 2021). The smallholder farmers in Zimbabwe typically rear various livestock, including cattle, goats, sheep, pigs and poultry, for various functions, including nutrition, draft power, income, store of wealth and manure to fertilise croplands (GoZ, 2026). However, the herd and flock sizes maintained by smallholder farmers are typically small, reflecting resource constraints and risk management strategies. These species form the backbone of rural agropastoral systems, contributing to household food security, income diversification and nutrient cycling.

Zimbabwe's agropastoral households cultivate a wide range of crops that affect both ecological adaptation and nutritional needs. Cereals such as maize, sorghum and millet provide staple carbohydrates while legumes like groundnuts, cowpeas and sugar beans (FNC, 2024; GoZ, 2026) contribute to protein and soil nitrogen fixation. Horticultural crops produced in nutrition gardens (GoZ, 2026), including leafy green vegetables, cabbage, tomatoes, carrots, and onions, can help enhance dietary diversity and micronutrient intake. Tubers such as sweet potatoes offer energy-dense food options and seasonal flexibility. This system creates synergistic feedback loops, crop residues serve as livestock feed, while animal manure enhances soil fertility, thereby improving crop yields (Musara et al., 2021). The mixed crop production complements livestock production, forming a resilient and integrated food system. Livestock also provide milk, meat and income, complementing staple crops to strengthen household food, nutrition and income security. By diversifying production and resource use, agropastoralism enables rural households to hedge against climatic shocks, market volatility, and seasonal food shortages, contributing to resilience and sustainable livelihoods (Manyanga et al., 2025; Musara et al., 2021).

Smallholder agropastoral systems are characterised by low livestock productivity and a yield gap for crops driven by multiple biophysical and socioeconomic constraints (FNC, 2024). The low crop yields are largely attributed to the reliance on rainfed agriculture, which has become increasingly unreliable due to climate change-induced rainfall variability (Brown et al., 2012; Muoni et al., 2025). Soil fertility decline, resulting from prolonged mismanagement and unsustainable land use practices (Musara et al., 2021), further exacerbates yield gaps (Gumindoga et al., 2024).In addition, pests and diseases significantly reduce yields, affecting both the crop stand and consequently the overall yield. The frequency of pest and disease outbreaks and the severity of impact have increased in recent years, partly due to climate change altering temperature and rainfall patterns (Svinurai et al., 2025). Common pests affecting maize include fall army worm (GoZ, 2018; GoZ, 2026), lepidopterous stem-borers, maize leafhoppers, termites, aphids (Chinwada, 2019), nematodes and rodents, alongside viral diseases, which compromise plant health, leading to economic losses for smallholder farmers (GoZ, 2026). Although farmers have access to training programs on good agronomic practices through government programs, the private sector and development partners, the adoption of these practices remains uneven across households (Manyanga et al., 2025). This is evident in the widespread use of suboptimal fertiliser applications (Manyanga et al., 2025), as many smallholders cannot afford recommended application rates, thereby perpetuating low productivity levels (Gumindoga et al., 2024).

Low productivity in livestock in smallholder agropastoral systems is a result of feed shortages and high disease prevalence, which contribute to elevated mortality rates and reduced livestock performance (FAO, 2021; Manyanga et al., 2025). Livestock play a critical role in these systems, not only as a source of food and income but also as a source of manure for crop production. However, the decline in herd sizes and productivity has led to limited manure availability, resulting in suboptimal manure applications (Gumindoga et al., 2024; Musara et al., 2021). This challenge is compounded by the widespread lack of soil testing, which prevents farmers from determining the optimum fertiliser blends and application rates needed to restore soil fertility (Gumindoga et al., 2024). Consequently, nutrient management remains inefficient, perpetuating low crop yields and undermining the resilience of smallholder farming systems.

Smallholder agropastoral systems continue to experience persistent yield gaps driven by soil fertility decline, climate variability, pest and disease pressure and limited adoption of improved agronomic practices (Kugedera et al., 2023). These challenges are compounded by the limited availability of organic fertiliser, farmers' constrained capacity to afford soil testing and the high cost of inorganic fertilisers. Although integrated nutrient management strategies are employed to mitigate soil fertility decline, application rates are often guided by

experimental observations and the limited availability of soil amendments, leading to persistently low productivity that compromises household food security, income and resilience. This study is therefore justified in systematically examining soil fertility constraints, fertiliser application practices, and economic implications in smallholder maize production. The study aimed to generate evidence that informs both agronomic interventions and supportive policy frameworks. By addressing the dual technical and economic dimensions of smallholder production, the study contributes to the design of a sustainable pathway for enhancing soil fertility, maize productivity, profitability and resilience in Zimbabwe's smallholder agropastoral production systems.

METHODOLOGY

The study employed a case study approach focusing on a total of 10 sites, comprising one on-station in Harare and nine off-station farms in Hwedza district. The farms were purposefully selected and identified in collaboration with the local agriculture extension staff as representative of the typical maize production system within the study community. The selection criteria included active maize cultivation, willingness to participate in the study, and representation of typical smallholder agropastoral conditions. Before the cropping season, soil samples were collected from farmers' fields using the zig-zag sampling technique at 0-20 centimetres (Harbitz, 2019; Leake & Haege, 2025). A composite sample was analysed in a certified laboratory for pH, macro- and micronutrients. The soil pH was determined using the calcium chloride method. Mineral nitrogen accounted for both the ammonium and nitrate forms. Available phosphorus was assessed using the resin extract method and reported as parts per million of P_2O_5. Exchangeable cations are expressed in milliequivalents per 100 grams or as milliequivalents per cent, with particular focus on magnesium, calcium, and potassium levels. Throughout the cropping season, the farmers maintained their usual cropping, nutrient and pest management practices. Farmers maintained records of different activities, including total inputs used, cost of inputs, the land preparation methods, seed variety, planting dates, weed control, and rainfall records.

The Hwedza District falls within agroecological zone IIb, which is characterised by relatively uniform rainfall patterns, thereby minimising climatic variability across sites. To standardise crop protection practices, pre-emergence herbicides, post-emergence herbicides, and pesticides for Fall Armyworm control were provided to all participating sites. This ensured that pest and weed management was consistent across treatments. Consequently, the main variable analysed was soil amendment and related inputs, allowing for a focused evaluation of their effects on crop performance under comparable agroecological conditions. Access to extension services was uniform across all sites, as farmers were supported by public agricultural extension officers. However, the level of mechanisation varied depending on each farmer's capacity to purchase or hire equipment, such as tractors for land preparation. Marketing of produce followed a dual system: farmers either sold through the informal or through the formal system managed by the Grain Marketing Board (GMB). The choice of marketing pathway was based on individual farmer preferences and was assessed as part of the study.

Yield was measured as grain, determined by harvesting maize from a plot area of 0.1 hectares per farmer and later extrapolated to one hectare. The standard formula for extrapolating grain yield from a small plot to one hectare is:

$$Yha = \frac{Yplot}{Aplot} \times 10000$$

Where:

- Yha = yield per hectare (kg/ha or t/ha)
- Yplot = yield measured from the trial plot (tonnes)
- Aplot = area of the trial plot in square meters (m^2)
- 10,000 = number of square meters in one hectare

DATA ANALYSIS

The data collected from soil sampling, farmer practices, yield measurement and economic assessment were subjected to both qualitative and quantitative analyses. Soil fertility parameters, including pH, nitrogen, phosphorus and potassium, were analysed using descriptive statistics to establish baseline conditions across study sites. Quantitative data were processed in Microsoft Excel, which facilitated statistical summaries, data tabulation and extrapolation of yields to a per-hectare basis. Grain yield data were standardised to tonnes per hectare and compared across households to identify variability in maize productivity. Qualitative data derived from farmer observations and management practices were analysed using the grounded theory approach. This involved systematic coding and categorisations of farmer responses to generate thematic insights into soil fertility management, input use and agronomic decision-making. This mixed methods framework ensured that both numerical performance indicators and farmer perspectives were integrated, providing a holistic understanding of agronomic practices adoption and the economic viability of maize production.

The economic analysis was conducted using production cost, gross margin, total revenue from grain crop yield and return per dollar invested. The price of manure and crop residues could not be determined, as there was no established market value within the study community. Since farmers for farmers who used the livestock manure, they owned the livestock that provided the manure, the manure itself was not a cost; instead, manure-related expenses were generated based on the labour and time required to transport manure to the fields and apply it to the cropland. Labour was calculated based on manhours required for each activity, applying the prevailing wage rates for hired labour. This approach was consistently used even when family farm labour was employed, which is common among smallholder farmers. This enabled the determination of profitability and the capacity of the farmers to reinvest in adequate inputs for the subsequent seasons. The assessment of farmers' adoption of different agronomic practices was conducted to see if the ability to afford inputs, prior farming experience, soil nutrient status, and pest and disease management challenges are linked to practice adoption and the economic viability of maize production.

RESULTS

Soil fertility status

At baseline, none of the nine participating farmers in Hwedza had undertaken soil testing, underscoring the need for initial diagnostic sampling to establish fertility status and guide subsequent agronomic interventions. Thereafter, soil samples were collected and submitted to a certified laboratory for analysis to determine the soil fertility status. The soil analysis across Hwedza and Harare revealed moderate to strong acidity, ranging between pH 4.3 and 6.0 (Table 1). These constraints on nutrient availability and necessitates liming, yet lime use is rare among smallholder farmers. Among the farmers in the study, none of them limed their soils, leaving soil acidity largely uncorrected. The exchangeable cations showed imbalances, with low calcium and potassium levels in most sites. Farmers reported that they do not test their soils and therefore remain unaware of the extent of soil acidity. They further cited the high cost and limited access to lime as the main reasons for not applying it. Despite the deficiencies, lime use remains rare due to cost and limited access. This persistent constraint reduces nutrient uptake efficiency and contributes to low yield responses.

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Table 1: Soil pH, nutrient availability, and cation exchange ranges across districts

Sample ID	Sample Ref	Texture	pH (Calcium chloride)	Mineral nitrogen parts/million Ammonia Nitrate N	Available Phosphorus Resin Extract parts/million of P_2O_5 (ppm)	Exchangeable cations mg equivalent per 100g/milliequivalent percent (me%)		
				Initial		Magnesium	Calcium	Potassium
733/SC	Hwedza	Medium-grained sandy loam	6	21	64	0.48	24.56	1.25
734/SC	Hwedza	Medium-grained sandy loam	5.6	61	34	1.43	2.76	0.76
735/SC	Hwedza	Medium-grained sand	5.2	15	23	0.42	1.32	0.2
736/SC	Hwedza	Medium-grained sandy loam	5.4	37	63	0.81	2.16	0.46
737/SC	Hwedza	Medium-grained sand	4.5	69	28	0.52	0.84	0.16
738/SC	Hwedza	Medium-grained sand	4.8	27	11	0.59	1.06	0.19
739/SC	Hwedza	Medium-grained sand	5	36	43	0.76	1.9	0.35
740/SC	Hwedza	Medium-grained sandy loam	5	25	12	0.67	1.29	0.23
741/SC	Hwedza	Medium-grained sandy loam	4.9	25	14	0.77	1.42	0.21
742/SC	Harare	Medium-grained sandy clay loam	5.2	36	47	3.46	7.23	0.36

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Lime and Maize Fertiliser Prescription Based on Soil Analysis

The laboratory prescriptions recommend substantial dolomitic lime (52% calcium carbonate ($CaCO_3$)) and 40% magnesium carbonate ($MgCO_3$), ranging from 300-2000kg per hectare, basal fertiliser in the form of compound D (7% Nitrogen, 14% Phosphorus, and 7% Potassium, plus 6–8.5% Sulphur) between 100-500kg. The recommended top dressing, in the form of ammonium nitrate (34.5% N), ranges from 300 to 650kg per hectare. These rates are agronomically sound but burdensome for smallholder farmers. Farmer applied reduced quantities ranging between 50 and 150kg of basal fertiliser compound D, with 30% of the farmers supplementing with organic soil fertilisers such as cattle manure. Farmers applied relatively low rates of top-dressing, ranging from 100 to 250 kg per hectare of ammonium nitrate. This adaptive strategy sustains crops but rarely achieves the yield levels required for profitability

Table 2: Prescribed lime and fertiliser application ranges for maize across sampled sites

Maize				
Sample Ref	Location	Dolomitic lime (kg ha)	Basal fertiliser (kg/ha) Compound D (7:14:7)	Top dressing Ammonium nitrate (kg/ha)
733/SC	Hwedza	0	100	600
734/SC	Hwedza	0	100	300
735/SC	Hwedza	600	100	650
736/SC	Hwedza	300	100	300
737/SC	Hwedza	2000	300	300
738/SC	Hwedza	1400	500	450
739/SC	Hwedza	1500	100	300
740/SC	Hwedza	1500	450	500
741/SC	Hwedza	1800	400	550
742/SC	Harare	900	100	300

Gap between Recommended and Actual Soil Amendments

The divergence between laboratory-prescribed application rates and the actual quantities of inorganic fertilisers applied by farmers highlights both affordability constraints and adaptive management practices. Table 2 summarises inorganic soil amendments recommended for maize production based on the soil analysis. The prescribed soil amendments include dolomitic lime to correct the soil's acidity, basal fertiliser, known as Compound D, which is made up of Nitrogen 7%, Phosphorus 14% and Potassium 7% plus 6–8.5% Sulphur respectively. The recommended top dressing is ammonium nitrates, which typically contain 34.5% nitrogen, providing both nitrate and ammonium forms of nitrogen, making it a quick-acting nutrient source. A total of 30% of the smallholder farmers also make use of organic fertilisers such as cattle manure, yet laboratory results and prescriptions provide no quantified guidance for organic fertiliser application. This omission perpetuates inconsistent use and limits the potential of organic soil amendments to improve soil structure, soil organic carbon,

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nutrient cycling and long-term soil fertility. Farmers also incorporate integrated soil fertility management practices, such as the use of nitrogen-fixing legume crops in crop rotations and intercrops, conservation agriculture, such as the planting basins with composting and mulching to manage soil fertility.

Table 3: Recommended vs. Actual Fertiliser Application in Maize Production

Input Type	**Lab recommended Rate (kg/ha)**	**Actual Farmer Practice (kg/ha)**	**Notes**
Dolomitic Lime	300 – 2000	0 – 300	Farmers rarely apply lime due to cost and limited access; acidity remains uncorrected.
Basal Fertiliser (Compound D 7:14:7)	100 – 500	50 – 150	Farmers often reduce rates or substitute with manure; phosphorus deficiency persists.
Top Dressing (Ammonium Nitrate)	300 – 650	100 – 250	Lower rates applied; nitrogen demand not fully met, limiting vegetative growth.
Organic Amendments (Manure, Compost, Humus, Termitaria)	No Supplementary use recommended	Widely applied, variable quantities	Farmers rely heavily on organic inputs to offset reduced inorganic fertiliser use.

Conventional soil testing focuses on inorganic nutrient deficiencies and neglects the role of organic amendments, leaving farmers without quantified guidance on their use. This omission discourages formal adoption of organic fertilisers, leading to inconsistent, suboptimal application based on availability or tacit knowledge rather than scientific recommendations. As a result, the potential of organic fertilisers to improve soil structure, nutrient cycling, and reduce reliance on costly inorganic fertilisers is undermined. While inorganic fertilisers remain central to yield improvement, smallholder farmers also depend on organic fertilisers for affordability and sustainability. Bridging the gap between laboratory prescriptions and farmer realities requires integrating organic fertiliser recommendations into soil testing protocols and supporting farmers' subsidies, credit schemes and input integrations. Such measures would enable balanced nutrient management, enhance soil health and strengthen resilience in crop production systems.

Farm-Level Variable Costs and Labour Allocation for Maize

Table 3 shows the variable costs incurred during maize production. The farms used a uniform seed rate of 25kg pr hectare. However, basal fertiliser, both organic and inorganic fertilisers, and top dressing varied together with labour inputs, reflecting differences in intensity and resource access. Labour demands were the highest for land preparation and pest control, averaging 60 manhours per hectare. Tasks such as manure application, weeding and shelling showed wide variation among farmers. This heterogeneity underscores the influence of input intensity and labour allocation on maize productivity. The total production cost ranged from m USD 401.27 for farm 733/SC to USD 785.68 for farm 742/SC, highlighting wide disparities in investment levels. These differences in cost structures provide the basis for subsequent analysis of yields, gross margins and return per dollar invested and illustrate how resource allocation strategies influence economic outcomes in smallholder maize systems.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue X October 2026

Table 4: Variable Input Costs and Total Production Coat for Smallholder Maize Farms

Item	Unit	Unit price	733/SC	734/SC	735/SC	736/SC	737/SC	738/SC	739/SC	740/SC	741/SC	742/SC
Variable cost		Unit price (USD)										
Maize seed	USD	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Basal fertiliser-Compound D	USD	36.5	91.3	82.1	146.0	127.8	155.1	109.5	155.1	160.6	76.7	219.0
Basal fertiliser-Livestock manure	USD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Top dressing -Ammonium nitrate	USD	42.5	46.8	170.0	174.3	180.6	127.5	170.0	99.9	138.1	99.9	255.0
Pre-emergency herbicide	USD	8.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Post-emergency	USD	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Pesticide for Fall Army Worm	USD	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Labour-Land preparation (ploughing, ridging, hoeing)	Man hours	0.8	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2
Labour-Fertiliser application (basal livestock manure)	Man hours	0.8	16.4	24.6	114.8	0.0	20.5	0.0	0.0	0.0	0.0	0.0
Labour-Planting & seed covering	Man hours	0.8	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
Labour-Basal fertilizer application	Man hours	0.8	8.5	7.7	13.7	12.0	14.5	10.3	14.5	15.0	7.2	20.5
Labour-Top dressing fertilizer application	Man hours	0.8	3.8	13.7	14.0	14.5	10.3	13.7	8.0	11.1	8.0	20.5
Labour-Weeding (2–3 rounds)	Man hours	0.8	4.5	16.4	16.8	17.4	12.3	16.4	9.6	13.3	9.6	24.6
Labour-Pest & disease control	Man hours	0.8	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2	49.2
Shelling (manual or mechanical)	Man hours	0.8	6.9	9.4	15.4	11.8	17.9	7.4	7.4	10.0	7.1	22.9
Total cost of production (USD)	**USD**		**401.3**	**547.1**	**718.1**	**587.3**	**581.3**	**550.4**	**517.8**	**571.4**	**431.6**	**785.7**

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Farm-level production costs, yields, and profitability indicators

Table 5 summarises the economic performance of the case study farms, presenting total production costs, maize yields, gross margins per tonne, and return per dollar investment (RDI). Production costs varied widely, ranging from USD 401.27 /hectare for farm 733/SC to USD 785.68 for farm 742/SC, reflecting differences in input intensity and labour allocation. Yields also showed substantial heterogeneity, from 0.93 t/ha for farm 733/SC to 3.10 t/ha for farm 742/SC. The observed yield falls in the same range, with a minimum yield of 1.5t/ha and a maximum of 3 t/ha (Basera, 2015)**.** The gross margin per hectare ranged from -USD 250.40 to +USD 147.67, with most farms operating at a loss; only farms 737/SC and 742/SC achieved a positive gross margin and return pr dollar invested (RDI). This highlights the economic challenges of smallholder maize production under current input use patterns. The return per dollar invested value ranged from losses of -USD0.48 to +USD0.25, with most farms recording negative returns, indicating that input costs outweigh revenue. Only farms 737/SC and 742/SC achieved positive RDI, reflecting limited profitability under prevailing practices. These results highlight the critical role of yield performance and efficient resource use in determining profitability rather than cost escalation alone.

Table 2: Costs, Yields, Gross Margins, and Return on Investment in Smallholder Maize Farms

Farm	Total cost of production (USD)/Ha	Maize yield (Tonnes/Ha)	Value of yield @$300/tonne (USD)	Gross margin/ tonne (USD)/Ha	Return per dollar investment (RDI) (USD)/ha
738/SC	$550.40	1.00	$300.00	-$250.40	-$0.45
739/SC	$517.77	1.00	$300.00	-$217.77	-$0.42
741/SC	$431.65	0.96	$288.00	-$143.65	-$0.33
733/SC	$401.27	0.93	$279.00	-$122.27	-$0.30
734/SC	$547.13	1.28	$384.00	-$163.13	-$0.30
740/SC	$571.35	1.35	$405.00	-$166.35	-$0.29
736/SC	$587.29	1.60	$480.00	-$107.29	-$0.18
735/SC	$718.09	2.08	$624.00	-$94.09	-$0.13
742/SC	$785.68	3.10	$930.00	$144.32	$0.18
737/SC	$581.33	2.43	$729.00	$147.67	$0.25
Average	**$569.19**	**1.57**	**$471.90**	**-$97.29**	**-$0.20**

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue X October 2026

Overall, the results highlight the dual challenge of cost recovery and investment efficiency in smallholder maize systems. The profitability depends not only on yield gains but also on on-site nutrient management and labour allocation strategies. These findings provide critical insights for designing interventions that balance input cost with productivity improvements, thereby enhancing the economic viability of maize production within the Hwedza community of Zimbabwe.

Gross margin sensitivity analysis for maize production

The gross margin sensitivity analysis in Figure 1 shows the relationship between maize yield and gross margin per hectare across the ten study farms. The analysis shows a positive linear trend, indicating that profitability increases with yield. The fitted regression equation, y=166.38x - 359.01, with R^2= 0.8067, suggests that yield explains approximately 81% of the variation in gross margin. Figure 1 shows that the gross margin increases significantly with yield. The break-even yield can be calculated by setting the gross margin to zero:

Equation 1: $Breakeven\ yield = 166.38x - 359.01$

$$X=\frac{359.01}{166.38}=2.16\ tonnes/\ hectare$$

Where: x = Maize yield (tonnes / ha)

Farms producing below the 2.16t/ha break-even yield recorded negative margins, while those exceeding this threshold achieved positive returns. This highlights the critical role of yield optimisation in ensuring economic viability.

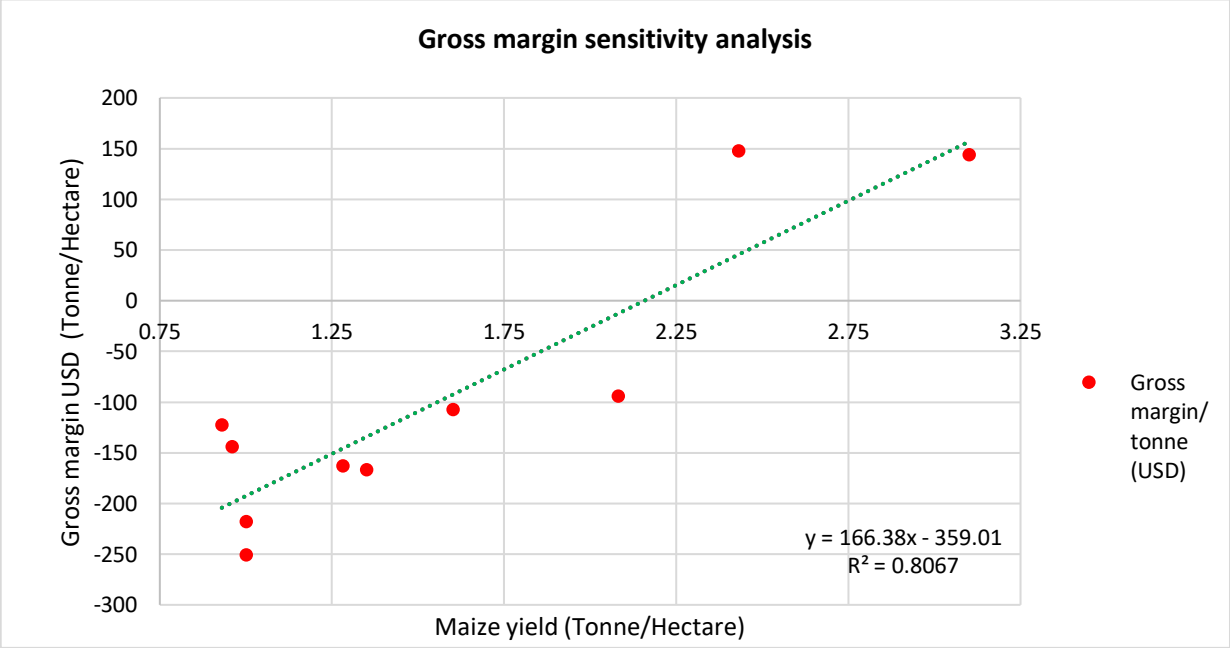

Figure 1: Gross margin sensitivity analysis for Maize Yield

Return per dollar investment sensitivity analysis for maize production

The comparative analysis of return per dollar invested across ten farms reveals pronounced disparities in investment efficiency. Figure 2 shows that only farms 737/SC and 742/SC achieved positive returns of $0.25 and $0.18 per dollar invested, respectively, indicating profitable operations. The rest of the farms recorded negative RDI values ranging from $0.13 to $0.45, reflecting losses where input costs exceed revenue. The pattern shows the limited financial resilience of smallholder maize production under the current cost structure and yield levels. These results highlight the need for targeted interventions to yield enhanced technologies.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue X October 2026

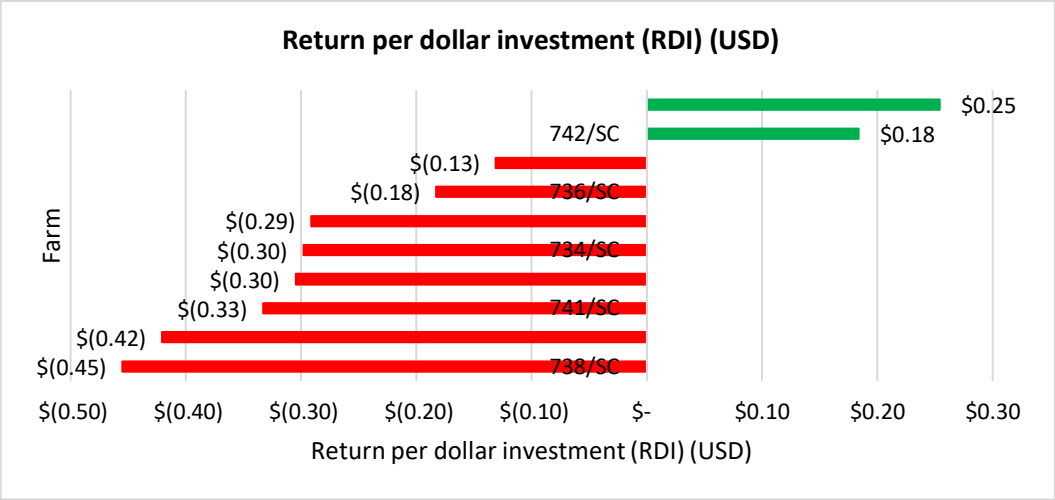

Figure 2: Maize Production Return per Dollar Investment

Yield vs Return per Dollar Investment Analysis

The relationship between maize yield and return per dollar invested exhibited a strong positive correlation, $y = 0.3019x - 0.6727$; $R^2 = 0.8619$, indicating that profitability improves markedly with increasing yield. The regression suggests a break-even yield of 2.23t/ha. Beyond this, each dollar invested begins to generate a positive return. The break-even yield can be calculated by setting the RDI to zero:

Equation 2:

$$\text{Breakeven yield} = 0.3019x - 0.6727$$

$$X = \frac{0.6727}{0.3019} = 2.23 \text{ tonnes per hectare}$$

Farms producing below this threshold experience negative RDI values, reflecting inefficiencies in input use and cost recovery. This trend underscores the importance of yield-enhancing interventions such as improved nutrient management and agronomic practices to achieve both cost recovery and investment efficiency in smallholder maize systems.

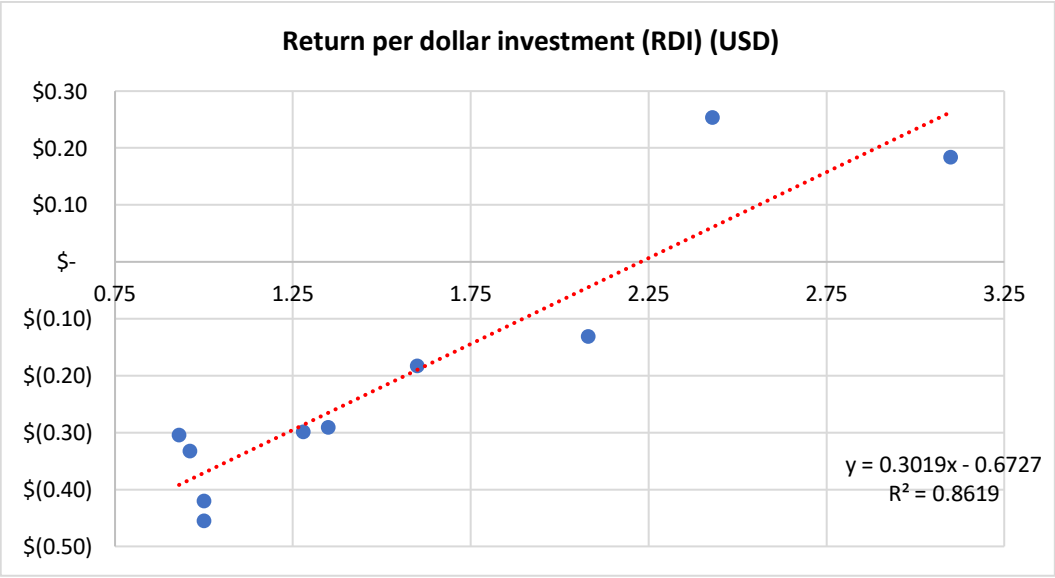

Figure 3: Maize return per dollar investment (RDI)

The results demonstrate that profitability in smallholder maize systems is constrained less by cost variation and more by yield performance. Systemic barriers such as soil acidity, high input costs, lack of lime use, and an

absence of organic fertiliser guidance limit maize productivity, resulting in an average maize yield of 1.57t/ha. The gross margin and RDI regressions both demonstrated strong positive associations with maize yield, but their breakeven thresholds differed slightly. The gross margin breakeven yield indicated that profitability was achieved at 2.16t/ha, where revenue equals production costs. In contrast, the RDI breakeven yield was 2.23t/ha, with yield beyond this point generating positive returns, reflecting the point at which each dollar invested began to generate positive returns. This distinction highlights that while farmers may technically recover costs at 2.16t/ha, they only achieve investment efficiency at 2.23t/ha. The dual threshold emphasises the challenge of balancing absolute cost recovery with relative efficiency, underscoring the importance of yield-enhancing interventions to secure both profitability and sustainable returns in smallholder maize systems

DISCUSSION

The soil fertility analyses across the nine sites in Hwedza and one in Harare reveal a consistent pattern of constraints that directly affect maize productivity. This study examined significant differences in maize productivity and profitability, with Hwedza and Harare constrained by soil acidity ranging between pH 4.3-6.0, low phosphorus, deficient potassium and patchy calcium and magnesium levels. Farmers did not apply lime, leaving acidity uncorrected, a finding consistent with the lime use remaining rare due to cost and access barriers (Soropa et al., 2018, 2022). The laboratory prescriptions recommended substantial corrective inputs, dolomitic lime 300–2000 kg/ha, basal fertiliser Compound D 100–500 kg/ha, and ammonium nitrate top dressing 300–650 kg/ha to address acidity and nutrient deficiencies. However, farmers applied significantly lower rates of lime, 0–300 kg/ha; Compound D, 50–150 kg/ha; and ammonium nitrate, 100–250 kg/ha. However, farmers applied significantly lower amounts, often supplementing with kettle manure. This gap reflects the gap between recommended and actual practice, reflecting affordability constraints and limited access to inputs, with integrated soil fertility management strategies sustaining crops but not necessarily achieving the yields required for profitability (Kanonge, 2014).

Smallholder farmers participate in both formal and informal maize markets. Informal markets are predominantly farm-gate sales and spot transactions within local business centres, where payments are made immediately, and prices are determined through bargaining. These spot markets, often referred to as black markets, transact in foreign currency, primarily in United States dollars. The formal maize market is regulated by the Grain Marketing Board (GMB), with USD-denominated producer prices set by government policy and gazetted through the Agriculture Marketing Authority (AMA). Payments may involve a mix of partial disbursements in both USD and local currency at the prevailing bank rate, and payments are only made after delivery. However, farmers reported that partial payments in local currency, coupled with delays in the formal market, reduced its attractiveness compared to informal spot markets. Such delays were also documented by Basera (2015), who found that 73–93% of transactions in the formal maize market were settled more than eight weeks after delivery by the GMB. Gross income was calculated at USD 300 per tonne, based on the value of maize grain sold by farmers in informal markets. This amount was lower than the Grain Marketing Board (GMB) price of USD 370.48 per tonne offered during the 2024–25 season. Yield outcomes across farms ranged from 0.93 to 3.10 t/ha, which is comparable to the findings of Basera (2015), who reported maize yields under smallholder production systems between 1.5 t/ha and 3.0 t/ha.

The production costs varied across farms, resulting in sharp profitability divergences; gross margins ranged from -USD 240.40 / ha to +USD147.67/ha, with only two firms achieving positive returns. The regression analysis confirmed yield as the dominant determinant of profitability, with gross margin break-even yield reached at 2.16t/ha and return on investment break-even yield of 2.23t/ha. These findings resonate with local evidence by Manyanga et al. (2025), who reported that smallholder profitability in Zimbabwe was strongly yield dependent, with resource-endowed households surpassing break-even thresholds, while poorer households remained below. Zingore & Njoroge (2022) similarly found that sandy soils respond poorly to nitrogen alone but yield significantly improved when manure is combined with balanced fertiliser, underscoring the importance of integrated nutrient management.

Regionally comparable dynamics have been documented in South Africa (Agbugba et al., 2020), who observed that irrigated smallholder farmers achieved higher gross margins than farmers who relied on rainfed agriculture.

This highlights the role of resource access and water management in maize yields. In Tanzania, Utonga (2022) showed that maize farming was profitable only when farmers accessed sufficient inputs and regulated markets. In Uganda, Ssekandi & Kyakuwa (2025) demonstrated that organic soil amendments such as vermicompost and biochar can achieve yields comparable to NPK fertilisers while improving soil health. These findings confirm that profitability in smallholder maize systems is highly yield sensitive, with breakeven threshold clustering around 2.16t/ha and 2.23t/ha, and that integrated nutrient management is essential for sustainable intensification and bridging the maize yield gap.

The evidence confirms that yield optimisation above 2.16t/ha and 2.23t/ha is a critical benchmark for profitability in smallholder maize systems. Systemic barriers such as soil acidity, high input costs, insufficient lime use and lack of organic fertiliser guidance prevent farmers from achieving recommended application rates and yields above the break-even. Addressing these challenges requires agronomic interventions through lime application, correct applications, balanced fertiliser use, systematic incorporation of organic amendments, and is guided by the 4R of nutrient stewardship (Johnston & Bruulsema, 2014). This should be combined with enabling policies such as input subsidies, credit schemes and market stabilisation; without such measures, smallholders remain locked in low-yield, loss-making cycles that undermine food security and resilience (Basera, 2015; Manyanga et al., 2025). By bridging technical and economic dimensions, smallholder farmers can achieve higher yields, positive gross margins and sustainable returns per dollar invested, thereby strengthening the resilience and sustainability of smallholder maize production in Hwedza district of Zimbabwe.

CONCLUSION

Despite relatively uniform production costs, yields varied widely between 0.93 and 3.10t/ha, resulting in sharp disparities in gross margins and returns on the dollar invested. The breakeven yield of 2.16t/ha and 2.23t/ha proved decisive; most farmers fell below this threshold and incurred losses, while only two firms achieved positive returns, both for their gross margins and the return paid per dollar invested. Sustainable intensification, therefore, requires a dual approach of addressing agronomic interventions such as lime application, balanced fertiliser use and systemic incorporation of organic soil amendments. This should be complemented by the implementation of enabling policies, including input subsidies, credit schemes and market stabilisation by bridging technical and economic dimensions, so that smallholder farmers can achieve profitability and resilience while contributing to sustainable maize production and household food security.

RECOMMENDATIONS

Based on the findings we recommend a dual strategy that integrates agronomic and policy interventions to enhance smallholder maize profitability agronomically farmers should adopt corrective soil fertility measures including lime application to address acidity balanced fertilizer use combining organic and inorganic soil of fertility amendments and systematic incorporation of manure to sustain nutrient cycling extension surfaces must prioritise training on integrated soil fertility management and promote record keeping to improve decision making at the policy level targeted input subsidies affordable credit schemes and timely market stabilization mechanisms are essential to reduce affordability barriers and ensure farmers can reach the break-even yield threshold of 2.16t/ha and 2.23t/ha strengthening cooperative structures and farmer groups will further enhanced access to inputs knowledge and markets thereby improving resilience and profitability Collectively these measures can help bridge productivity gaps reduce systematic soil fertility losses and economic losses and contribute to sustainable intensification of smallholder maize systems while offering lessons for regional agricultural policy frameworks.

LIMITATIONS OF THE STUDY

This study provides important insights into soil fertility management and maize profitability; however, several limitations must be acknowledged. The analysis was based on only ten representative soil samples, which may not adequately capture the spatial variability in soil conditions across different production systems and agroecological zones. This limited sampling reduces the generalisability of the findings and constrains the ability to draw robust conclusions about broader farming contexts. Hence, future studies should explicitly address these

limitations by expanding the number of sampled farms and soil profiles to better capture spatial variation and improve representativeness.

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